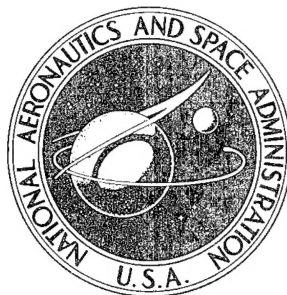


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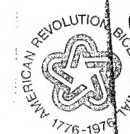
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NOLIN - A NONLINEAR
LAMINATE ANALYSIS PROGRAM

John J. Kibler

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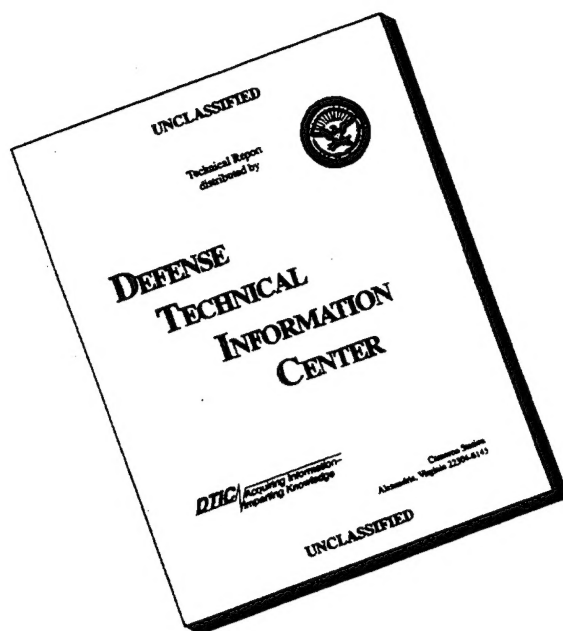
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NOLIN
A NONLINEAR LAMINATE ANALYSIS PROGRAM

by
John J. Kibler

SUMMARY

A nonlinear, plane-stress, laminate analysis program, NOLIN, has been developed which accounts for laminae nonlinearity under inplane shear and transverse extensional stress. The program determines the nonlinear stress-strain behavior of symmetric laminates subjected to any combination of inplane shear and biaxial extensional loadings. The program has the ability to treat different stress-strain behavior in tension and compression, and predicts laminate failure using any or all of maximum stress, maximum strain, and quadratic interaction failure criteria.

A second program, UNI, has been developed which computes elastic constants and thermal coefficients of expansion for laminae, from constituent properties, to aid in compiling input for the NOLIN program. Laminae properties can be computed for isotropic or transversely isotropic fibers in an isotropic matrix. In addition, the nonlinear inplane shear stress-strain curves are computed for the laminae by computing the Ramberg-Osgood shear stress parameter.

This document provides brief descriptions of both programs, a description of the flow of information through the NOLIN program, and detailed descriptions of the input required for each program. Sections are provided with sample problems and sample program output, along with complete listings of each program.

1. NOLIN Program Description

1.1 Introduction

The NOLIN program codifies a nonlinear, plane-stress, laminate analysis wherein the nonlinear behavior of the laminae under inplane shear and transverse extensional stresses are taken into account. Both the underlying analytical development and the computer program are sufficiently general to enable the user to study the nonlinear behavior of a symmetric laminate subjected to any combination of inplane shear and biaxial extensional loadings. Contained in this document are a detailed description of the input required to use the NOLIN program, as well as a description of the theoretical developments upon which the program is based. For a complete theoretical description the reader is referred to Ref. 1.

In unidirectional, fiber-reinforced laminae, the transverse extensional and, particularly, the inplane shear stress-strain relationships cannot be accurately characterized as linear. The NOLIN program allows for nonlinear representations by permitting these stress-strain relationships to take the form of Ramberg-Osgood nonlinear relationships. The introduction of these nonlinear, Ramberg-Osgood type constitutive relationships into a laminate analysis then leads to a set of nonlinear equations involving the laminae stress components as unknowns. The program then solves this set of equations by means of a generalized, Newton-Raphson procedure to give the laminae stresses and strains corresponding to the applied boundary stresses.

The theoretical development for this nonlinear, laminate analysis incorporates total deformation theory with Ramberg-Osgood type stress-strain characterizations to formulate the governing nonlinear equations. At the outset the compliance tensor is assumed to be the sum of two tensors, the components of one are the usual components associated with linear,

orthotropic, plane-stress elasticity theory, while the second tensor contains the nonlinear elements. By assuming a quadratic interaction of the stress components, and requiring the constitutive relationship to reduce to the relationships for the uniaxial stress cases of inplane shear and transverse extension, the elements of the nonlinear compliance tensor are explicitly determined.

Having the nonlinear laminae constitutive relations, the usual methods of laminate theory are then utilized to obtain the governing, nonlinear equations for the laminate. As in linear, laminate theory, the strains of the individual laminae are first rotated to a common set of laminate axis, and the laminate compatibility relations requiring the corresponding strains of the individual laminae to be equal are then employed. In addition, equilibrium at the laminate boundaries is invoked. In this way the required number of equations involving the unknown laminae stresses are formulated.

The program solution procedure for the set of nonlinear equations involving the laminae stress components is a Newton-Raphson technique generalized to accomodate systems of equations. The starting point for the solution procedure is taken as the solution of the associated, linear laminate problem, where the associated linear problem is obtained by ignoring all nonlinear terms.

Incorporated into the program are three different failure criteria, maximum stress, maximum strain and a quadratic interaction criteria. Any or all of these may be employed by the program user. Unfortunately, the nonlinear aspects of this program preclude the generation of strength envelopes since linear extrapolation is not valid here. Instead a sequence of combined loadings may be run.

The governing equations are formulated so that the three stress components in each lamina are the unknowns. Thus, for an N-layered laminate, the problem is formulated in terms of 3N unknowns. To obtain solutions, 3N equations are then required, and these equations consist of three equilibrium equations and 3(N-1) compatibility equations satisfying strain compatibility between adjacent laminae. The three equations of equilibrium for a laminate under a combined state of stress are,

$$\begin{aligned} \sum_{k=1}^N \sigma_{11}^{(k)} t_k &= N_{11} \\ \sum_{k=1}^N \sigma_{22}^{(k)} t_k &= N_{22} \\ \sum_{k=1}^N \sigma_{12}^{(k)} t_k &= N_{12} \end{aligned} \quad (6)$$

Where N_{11} , N_{22} and N_{12} are the applied stress resultants, t_k the thickness of the kth lamina, and subscripts 1 and 2 denote the laminate axes. The 3(N-1) equations of strain compatibility are,

$$\begin{aligned} \epsilon_{11}^{(k)} &= \epsilon_{11}^{(k-1)} \\ \epsilon_{22}^{(k)} &= \epsilon_{22}^{(k-1)} \\ \epsilon_{12}^{(k)} &= \epsilon_{12}^{(k-1)} \end{aligned} \quad (7)$$

$$k = 2, 3, \dots, N$$

Equations (6) and (7) are the 3N equations required for the solution of the nonlinear laminate problem. When the stress-strain relations given by equations (2), (4) and (5) are transformed to the laminate reference axes and substituted into equations (7), the governing equations can be expressed

in functional form as,

$$F_k (\sigma_1, \sigma_2, \dots, \sigma_1^2, \dots) = 0 \quad (8)$$

$$k = 1, 2, \dots, 3N$$

1.3 Method of Solution

Solutions of equations (8) for the 3N stress components are obtained by employing a Newton-Raphson iterative scheme. The functions F_k are first expanded in Taylor series about an approximate set of initial stresses, σ_j^0 . Considering only the first order terms of these series,

$$F_k = F_k^0 + \left(\frac{\partial F_k}{\partial \sigma_j} \right) \bigg|_{\sigma_j^0} \cdot \Delta \sigma_j \quad (9)$$

$$j, k = 1, 2, \dots, 3N$$

By writing,

$$\Delta \sigma_j = \sigma_j - \sigma_j^0$$

where σ_j are the solution values, equations (9) can be rewritten to give

$$\sigma_j = \sigma_j^0 - \left(\frac{\partial F_k}{\partial \sigma_j} \right) \cdot F_k^0 \quad (10)$$

$$j, k = 1, 2, \dots, 3N$$

For clarity, the notation in equations (10) is, in expanded form,

$$\sigma_j = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \vdots \\ \sigma_N \end{bmatrix} \quad (11)$$

$$\sigma_j^{\circ} = \begin{bmatrix} \sigma_1^{\circ} \\ \sigma_2^{\circ} \\ \cdot \\ \cdot \\ \cdot \\ \sigma_N^{\circ} \end{bmatrix} \quad (12)$$

$$F_k^{\circ} = \begin{bmatrix} F_1^{\circ} \\ F_2^{\circ} \\ \cdot \\ \cdot \\ \cdot \\ F_N^{\circ} \end{bmatrix} \quad (13)$$

and,

$$\left(\frac{\partial F_k}{\partial \sigma_j} \right) \sigma_j^{\circ} = \begin{vmatrix} \frac{\partial F_1}{\partial \sigma_1} & \frac{\partial F_1}{\partial \sigma_2} & \dots \\ \frac{\partial F_2}{\partial \sigma_1} & \frac{\partial F_2}{\partial \sigma_2} & \dots \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{vmatrix} \quad \sigma_j = \sigma_j^{\circ} \quad (14)$$

The solution for σ_j in equation (10) may be taken as the approximate, initial stress values for the next iteration step, and this process repeated until a result is obtained within some desired accuracy. After the stresses are obtained and transformed to the laminae natural axes, the corresponding laminae strains are determined from equations (1), (2) and (5).

1.4 Computer Program

The flow chart for the computer program is shown in Fig. 1. The major sections of the program are the formation of the governing equations, the Newton-Raphson solution procedure and the failure checks.

Using the computer program notation, the governing equations take the form,

$$[A] \cdot \overline{SG} + \overline{B} = \overline{SGO} \quad (15)$$

Where \overline{SG} and \overline{SGO} are the stress solution vector and the applied stress vector, respectively. A is a matrix of constant elements which are the coefficients of the linear terms in the solution, and \overline{B} is a vector containing the nonlinear terms in the solution. The set of equations (15) are equivalent to equations (8). If in equation (15) the vector \overline{B} is set to zero, the resulting equation

$$[A] \cdot \overline{SG} = \overline{SGO} \quad (16)$$

is the linear laminate solution. The stress vector, \overline{SG} , as determined from equation (16) is taken as the initial approximation for the stress vector in the Newton-Raphson procedure.

For the Newton-Raphson procedure it is necessary to formulate the derivative of $([A] \cdot \overline{SG} + \overline{B})$ in equation (15) with respect to σ_j as well as the vector

$$\overline{DC} = ([A] \cdot \overline{SGO} + \overline{B} - \overline{SGO}) \quad (17)$$

The vector \overline{DC} corresponds to the vector \overline{F}_f^o in equation (10), and an explicit evaluation of \overline{DC} is obtained by using the current, approximate value for the solution stress vector, \overline{SC} . The derivative of $([A] \cdot \overline{SG} + \overline{B})$ is designated \overline{DB} in the computer program, and is equivalent to the matrix $(\partial F_k / \partial \sigma_j) \sigma_j^o$ in equation (10). An explicit evaluation of \overline{DB} is also obtained by using the current, approximate value for the solution stress vector, \overline{SG} .

In the program, the external loading is applied in increments. The approximate solution stress vector for the first load increment and the first Newton-Raphson iteration is determined from equation (16). For the second and third load increments, the approximate solution stress vectors for the first iteration are taken as the final solution stress vectors from the previous increments. Solutions for subsequent load increments are initiated by the following algorithm:

$$\begin{aligned} (SG_i + 1)_{\text{INITIAL}} &= (SG_i)_{\text{FINAL}} * (\text{FACTOR}) \\ (\text{FACTOR}) &= \frac{i(i-2)}{(i-1)^2} \frac{(SG_i)_{\text{FINAL}} - (SG_{i-1})_{\text{FINAL}}}{(SG_i)_{\text{FINAL}}} \end{aligned} \quad (18)$$

The convergence and divergence criteria employed in the program are contained in the following expressions:

$$\begin{aligned} |(SG_{i+1} - SG_i)/SG_i| &\leq \epsilon \\ |(SG_{i+1} - SG_i)/SG_i| &< \lambda \end{aligned} \quad (19)$$

Where SG_i and SG_{i+1} are the solution vectors obtained from the i^{th} and $i+1^{\text{th}}$ iterations. Usually values of 10^{-3} and 10^{-4} are taken for ϵ and λ , respectively. However, the other values may be input as data to the program. In addition, the maximum number of iterations to be allowed is input as data. Ten iterations have been found to be sufficient for most problems.

The program contains three failure criteria, maximum strain, maximum stress, and a quadratic interaction criteria. After a solution is obtained for each load increment any or all of these failure criterias may be applied to check for laminae failure.

The maximum stress and maximum strain failure criteria check, respectively, the laminae stress or strain values in

the fiber, and transverse fiber directions against the material allowables. These allowables are input to the program as data. The quadratic criteria is given by

$$\begin{aligned}
 & A_{11} \sigma_{LL}^2 + A_{22} \sigma_{TT}^2 + A_{44} \sigma_{LT}^2 \\
 & + A_{12} \sigma_{LL} \sigma_{TT} + B_1 \sigma_{LL} + B_2 \sigma_{TT} = 1
 \end{aligned}
 \tag{20}$$

where the coefficients are functions of the allowable stress

$$\begin{aligned}
 A_{11} &= \frac{1}{F_L^T F_L^C} & B_{11} &= \frac{1}{F_L^T} - \frac{1}{F_L^C} \\
 A_{22} &= \frac{1}{F_T^T F_T^C} & B_{22} &= \frac{1}{F_T^T} - \frac{1}{F_T^C} \\
 A_{44} &= \frac{1}{(F^S)^2}
 \end{aligned}
 \tag{21}$$

F_L^t and F_L^c are the allowable tension and compression stresses in the longitudinal direction, F_T^t and F_T^c are the allowable tension and compression stresses in the transverse direction, and F^S is the allowable shear stress. The coefficient A_{12} is input as data to the program, or a default null value is used.

If a failure criteria is satisfied at the end of a load increment, the program determines the failure load through linear interpolation. If all failure criteria are being checked, and not all indicate failure during the same load increment, the program continues loading until all criteria indicate failure.

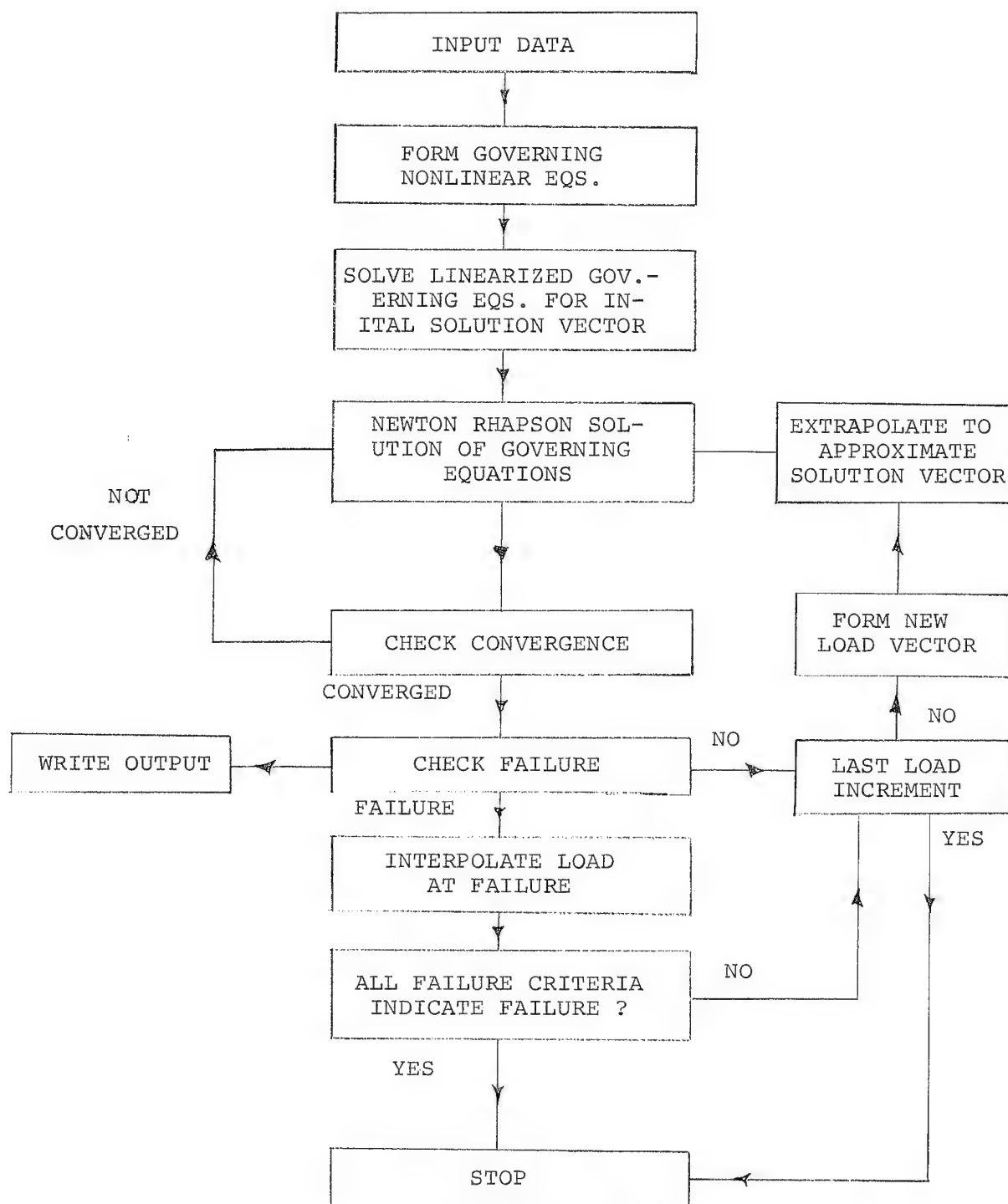


Figure 1 - Solution flow Chart

2. NOLIN PROGRAM USERS GUIDE

2.1 Program Description

This section describes the input data requirements for NOLIN (version 2 mod 2). Input procedures have been streamlined wherever possible by using one NAMELIST statement, hence eliminating any input under format control.

The input flow diagram and input description provide all information necessary to specify input data sets capable of exercising all program options.

2.2 Input Description

The initial data required is a message of five cards of alphanumeric descriptive information describing the problem being solved and printed as a title on the output. These five cards may be left blank, but must be included ahead of the first NAMELIST deck in the data. This descriptive message is read only once at the beginning of the program execution. The multiple case feature of running successive computations is accomplished by supplying multiple NAMELIST data sets with the changed variables indicated.

The following is a description of the input variables required for execution of the program. Where appropriate, default or suggested values are indicated. The following data are supplied through NAMELIST "DATA":

Program Option Parameters

IOPT:	Ramberg-Osgood parameter sentinel.
	IOPT=1: Input R-O parameter directly.
	IOPT=2: Determine parameters from stress-strain curve-fit routine.
COPT:	Curve-fit sentinel, (exercised if IOPT=2)
	COPT=1: Same stress-strain data for each layer.
	COPT=2: Different sets of data for each layer.

EOPT: Exponent option, (exercised if IOPT=2)
 EOPT=1: Determine exponents from curve-fit routine.
 EOPT=2: Input exponents to curve-fit routine.

Solution Accuracy Parameters

KSGM: No. of load increments, maximum = 50 increments.
 SMLT: Load increment multiple, maximum number of Newton-Raphson iterations, default is 100.
 EPS: Convergence criteria for Newton-Raphson analysis, default value is 10^{-3} .
 UPBD: Divergence criteria during Newton-Raphson analysis, default value is 20000.
 INMT: Incrementation estimate method, default value is 2.

Layer Description

NLAY: Number of laminate layers (max. is 20).
 THICK(LAY): Thickness of each layer.
 THETA(LAY): Orientation of each layer in degrees.
 MATYPE(LAY): Material kind of each layer (maximum number of different materials is 20).

Material Description

E11 (MATYPE): Lamina longitudinal modulus.
 E22 " Lamina transverse modulus.
 G12 " Lamina shear modulus.
 V12 " Lamina major Poisson's ratio.
 S11T " Lamina longitudinal tensile strength.
 S11C " Lamina longitudinal compressive strength.
 S22T " Lamina transverse tensile strength.

S22C (MATYPE):		Lamina transverse compressive strength.
S12	"	Lamina in-plane shear strength.
EP11T	"	Lamina longitudinal tensile strain.
EP11C	"	Lamina longitudinal compressive strain.
EP22T	"	Lamina transverse tensile strain.
EP22C	"	Lamina transverse compressive strain.
GAMA	"	Lamina in-plane shear strain.
A12	"	Lamina interaction term for quadratic interaction criteria - default value is 0.0.
STY	"	Ramberg-Osgood tension constant
SCY	"	Ramberg-Osgood compression constant
TY	"	Ramberg-Osgood shear constant.
XM	"	Ramberg-Osgood shear exponent (default value is 3.0).
XN	"	Ramberg-Osgood tension exponent (default value is 3.0).

Stress-Strain Data (input in IOPT=2)

IPTS:		Number of stress-strain data points.
SIG11(I,MATYPE):		IPTS values of longitudinal lamina stresses for each material type.
SIG22	"	IPTS values to transverse lamina stresses for each material type.
SIG12	"	IPTS values of in-plane shear stresses for each material type.
EPS11	"	IPTS values of longitudinal lamina strains for each material type.
EPS22	"	IPTS values of transverse lamina strains for each material type.
EPS12	"	IPTS values of in-plane shear strain for each material type.

Applied Loading and Failure Criteria

SO11: Initial axial stress applied to laminate.
SO22: Initial transverse stress applied to
laminate.
SO12: Initial shear stress applied to laminate.
IFCN: Failure criteria sentinel
IFCN=1: ultimate stress
IFCN=2: ultimate strain
IFCN=3: quadratic interaction
IFCN=4: all failure criteria
STIFF: Ratio of final to initial laminate
stiffness which constitutes failure
due to stiffness reduction, default
value is 0.10.

3. UNI PROGRAM

3.1 Description

Program UNI computes the elastic properties, thermal expansion coefficients and the Ramberg-Osgood shear stress parameter for the unidirectional fiber bundle or the lamina. The fiber may be isotropic or transversely isotropic and the matrix is isotropic. The effective elastic properties of the composite are calculated from the composite cylinder assemblage model proposed by Hashin and Rosen [2] and the thermal expansion coefficients from the analytical results of Ref. [3]. The program also calculates the Ramberg-Osgood shear stress parameter of the matrix as outlined in Ref. [1].

The UNI program takes constituent properties as input and computes laminae properties as output. The output properties provide all the information required as input to the NOLIN program. The program accepts families of fiber and matrix materials such that an array of laminae properties can be generated. This feature can be especially useful for sensitivity analyses. All input to UNI is accomplished through a single NAMELIST statement "UNID".

3.2 Input Description

The following describes the variables required for the execution of UNI through NAMELIST "UNID".

Program Control Variables

NF:	No. of fibers, max. is 20.
NM:	No. of matrices, max. is 20.
NVM:	No. of matrix vol. fractions, max. is 20.

Matrix Properties, J=1, NM

EM(J): Young's modulus for Jth matrix.
RHOM(J): Density of Jth matrix.
ANUM(J): Poisson ratio for Jth matrix.
ALPM(J): Coef. of thermal expansion for Jth
matrix required only if ISTS=1.
ROMS(J): Shear stress Ramberg-Osgood parameter
for Jth matrix required only if
NONLIN = 1.

Isotropic Fiber Properties, J=1, NF

The following variables are required when ISOT=1:

EF(J): Young's modulus for Jth fiber.
ANUF(J): Poisson ratio for Jth fiber.
RHOF(J): Density of Jth fiber.
ALPF(J): Coef. of thermal expansion for Jth
fiber (required only if ISTS=1).

Transversely Isotropic Fiber Properties, J=1 NF

The following variables are required when ISOT=2:

EFA(J): Axial Young's modulus for Jth fiber.
EFT(J): Transverse Young's modulus for Jth fiber.
ANUFA(J): Axial Poisson ratio for Jth fiber.
GFA(J): Axial shear modulus for Jth fiber.
ANUFT(J): Transverse Poisson ratio for Jth fiber.
ALPF(J): Axial thermal expan. coef. for Jth
fiber (required only if ISTS=1).
ALPFT(J): Transverse thermal exp. coef. for Jth fiber.
(required only if ISTS=1).

Laminae Volume Fractions, J=1, NVM

VM(J): Jth volume fraction of matrix material.

The UNI program computes laminae properties for all combinations of fibers, matrix materials, and volume fractions which are supplied as input. That is, there are a total of $NF \times NM \times NVM$ materials formed from the input. Within a given run the total number of materials ($NF \times NM \times NVM$) must be less than 200.

The following is a description of the properties computed by UNI and printed as output:

Calculated Thermo-Elastic Constituent Parameters

GFT(J): Transverse shear modulus for Jth fiber.
GF(J): Shear modulus for Jth fiber.
GM(J): Shear modulus for Jth matrix.
AKF(J): Plane strain bulk modulus for Jth fiber.
AKM(J): Plane strain bulk modulus for Jth matrix.

Effective Thermo-Elastic Parameters

AKTS(J): Effective trans. bulk modulus for Jth material.
EAS(J): Effective axial Young's modulus for Jth material.
ETS(J): Effective trans. Young's modulus for Jth material.
ANUAS(J): Eff. Poisson ratio (unidirectional axial stress) for Jth material.
ANUTS(J): Eff. Poisson ratio (in transverse plane) for Jth material.
GAS(J): Eff. shear modulus (in fiber planes) for Jth material.
GTS(J): Eff. shear modulus (in trans. planes) for Jth material.

ALPAS(J): Eff. (fiber direction) thermal exp.
coef. for Jth material.
ALPTS(J): Eff. (trans. direction) thermal exp. coef.
for Jth material.
RHOS(J): Bulk density for Jth material.
ROCOMP(J): Ramberg-Osgood shear stress parameter
for Jth material.

4. SAMPLE PROBLEMS

The purpose of this section is to present several sample problems which illustrate the capabilities of both the UNI and the NOLIN programs. Both the program input and output are listed at the end of this section to aid in understanding the program.

4.1 UNI - Sample Problems

4.1.1 Laminae properties for Thornel 50 fibers in two carbon matrices have been determined. The transversely isotropic fiber option has been used to model the Thornel 50 fibers, and a Ramberg-Osgood shear stress parameter is included for the two matrix materials.

The input data and the resulting output data are given in sections 4.1.2 and 4.1.3. Note that the constituent properties are mirrored in the program output along with the required computed constituent properties. The effective thermoelastic properties for the 1-D laminae are printed on the second page of output. Units are consistent throughout the program such that the units need only be consistent for the constituent properties, in this case properties were input as MN/M^2 .

The second sample problem combines KEVLAR-49 fibers with a range of matrix properties to obtain the 1-D composite properties. A list of input data for this case and the corresponding program output are shown in sections 4.1.2 and 4.1.3. It is interesting to note that an order of magnitude change in matrix modulus results in a factor of five change in transverse modulus and transverse shear modulus.

4.1.2 UNI SAMPLE PROBLEMS - INPUT CARDS

C UNI DATA

```

$DATAONE
NF=1, NM=2, NV=2,
EFA(1)=3.8E+03, EFT(1)=7.2E+03, GFA(1)=.38E+04,
ANUEFA(1)=0.1, ANUEFT(1)=0.1,
RHOF(1)=1.,
EM(1)=1.7E+14, 3.4E+14,
ANUM(1)=2*0.2,
RHOM(1)=2*1.,
VM(1)=0.4, 0.6,
ROMS(1)=2*3.0,
ALPF(1)=5.E-07,
ALPFT(1)=5.0E-06,
ALPM(1)=2*1.4E-16*
$DATAONE
NF=1, NM=10, NV=1,
EFA(1)=1.3E+03, EFT(1)=1.2, RHOF(1)=1.,
EFT(1)=9.78E+03, ANUEFT(1)=0.2, GFA(1)=.17E+03,
EM(1)=.5E+03, 1.E+03, 1.5E+03, 2.E+03, .5E+03, 3.E+03,
3.5E+03, 4.E+03, 4.5E+03, 5.E+03,
ANUM(1)=10*1.2, RHOM(1)=10*1.,
VM(1)=0.4,
ALPF(1)=-6.1E-17, ALPFT(1)=3.83E-06,
ALPM(1)=10*1.39E-16*

```

4.1.1.3 UNI SAMPLE PROBLEM OUTPUT NO. 1

FIBER NO.	E(F)	NU(F)	G(F)	K(F)	RHO(F)	ALPHA(F)
1	3.60000E+05	.10000	13800	4018.4	1.0000	5.00000E-07
1	7230.0	.10000	1286.4	4018.4	1.0000	3.60000E-06

MATRIX NO.	E(M)	NU(M)	G(M)	K(M)	RHO(M)	ALPHA(M)
1	17000	.20000	7093.3	11606	1.0000	1.40000E-06
2	34000	.20000	14167	23611	1.0000	1.40000E-06

MATRIX NO.	R-O-S(M)
1	3.0000
2	3.0000

EFFECTIVE THERMO-ELASTIC PARAMETERS

F	M	MATERIAL	V(M)	E(M)* E(T)*	NU(M)* NU(T)*	G(M)* G(T)*	K(T)* RHO*	ALPHA(A)* ALPHA(T)*
1	1	1	.40000	2.34833E+05 10303	.15351 .16120	15471 4475.1	6210.6 1.00000	5.23229E-07 2.51547E-06
				R-O PARAMETER = 3.11794E+00				
1	1	2	.60000	1.62270E+05 12302	.17215 .18709	9175.0 5241.3	7667.0 1.0000	5.52901E-07 2.13356E-06
				R-O PARAMETER = 2.76561E+00				
1	2	3	.40000	2.41649E+05 14403	.16535 .17125	17946 6180.8	8778.4 1.00000	5.46548E-07 2.27233E-06
				R-O PARAMETER = 3.11794E+00				
1	2	4	.60000	1.72441E+05 10563	.18093 .19209	14019 8199.3	12234 1.0000	6.01733E-07 1.94690E-06
				R-O PARAMETER = 2.96541E+00				

PROBLEM NO. 2 OUTPUT

FIRER NO.	E(F)	NU(F)	S(F)	K(F)	RHO(F)	ALPHA(F)
1	1.30000E+05	.20000	1170.0	6158.8	1.0000	-6.10000E-07
1	9780.0	.20000	4075.0	6158.8	1.0000	1.83000E-06

MATRIX NO.	E(M)	NU(M)	S(M)	K(M)	RHO(M)	ALPHA(M)
1	500.00	.20000	208.33	347.22	1.0000	1.39000E-05
2	1000.0	.20000	416.67	694.44	1.0000	1.39000E-05
3	1500.0	.20000	625.00	1041.7	1.0000	1.39000E-05
4	2000.0	.20000	833.33	1388.9	1.0000	1.39000E-05
5	2500.0	.20000	1041.7	1736.1	1.0000	1.39000E-05
6	3000.0	.20000	1250.0	2083.3	1.0000	1.39000E-05
7	3500.0	.20000	1458.3	2430.6	1.0000	1.39000E-05
8	4000.0	.20000	1666.7	2777.8	1.0000	1.39000E-05
9	4500.0	.20000	1875.0	3125.0	1.0000	1.39000E-05
10	5000.0	.20000	2083.3	3472.2	1.0000	1.39000E-05

MATRIX NO. P-O-S(M)

1	3.0000
2	3.0000
3	0.
4	0.
5	0.
6	0.
7	0.
8	0.
9	0.
10	0.

EFFECTIVE THERMO-ELASTIC PARAMETERS

F	M	MATERIAL	V(M)	E(A)* E(T)*	NU(A)* NU(T)*	G(A)* G(T)*	K(T)* RHO*	ALPHA(A)* ALPHA(T)*
1	1	1	.40000	78200 4596.5	.20000 .21564	508.35 656.64	1019.8 1.00000	-5.72890E-07 6.33022E-06
				R=0 PARAMETER = 3.11794E+00				
1	2	2	.40000	78000 2803.9	.20000 .21802	748.63 1451.0	1799.4 1.00000	-5.35969E-07 6.42491E-06
				R=0 PARAMETER = 3.11794E+00				
1	3	3	.40000	78600 3760.0	.20000 .21920	903.44 1542.0	2419.6 1.00000	-4.99237E-07 6.51767E-06
				R=0 PARAMETER = 0.				
1	4	4	.40000	78800 4543.4	.20000 .21973	1020.2 1862.4	2928.7 1.00000	-4.62690E-07 6.60856E-06
				R=0 PARAMETER = 0.				
1	5	5	.40000	79000 5202.6	.20000 .21990	1116.8 2132.4	3357.3 1.00000	-4.26329E-07 6.69761E-06
				R=0 PARAMETER = 0.				
1	6	6	.40000	79200 5769.5	.20000 .21985	1201.4 2364.8	3725.5 1.00000	-3.90152E-07 6.78490E-06
				R=0 PARAMETER = 0.				
1	7	7	.40000	79400 6265.5	.20000 .21969	1278.2 2568.5	4047.5 1.00000	-3.54156E-07 6.87046E-06
				R=0 PARAMETER = 0.				
1	8	8	.40000	79600 6706.1	.20000 .21945	1349.8 2749.6	4333.1 1.00000	-3.18342E-07 6.95435E-06
				R=0 PARAMETER = 0.				
1	9	9	.40000	79800 7102.3	.20000 .21917	1417.6 2912.8	4589.8 1.00000	-2.82707E-07 7.03662E-06
				R=0 PARAMETER = 0.				
1	10	10	.40000	80000 7462.7	.20000 .21887	1482.7 3061.3	4822.9 1.00000	-2.47250E-07 7.11730E-06
				R=0 PARAMETER = 0.				

***** NO. 100 TERMINATED *** *****

4.2 NOLIN Sample Problems

4.2.1 The sample problems for the NOLIN program have been chosen to exercise several options of the program. Graphite/Epoxy and Boron/Aluminum laminates have been modeled, employing material properties derived from the Air Force Composites Design Guide.

The initial problem is a $\pm 30^\circ$ Boron/Aluminum laminate under uniaxial tensile loading. Ramberg-Osgood parameters were input, with exponents set equal to 3.0, and a maximum strain failure criteria was employed. The input data and the program output follow in sections 4.2.2 and 4.2.3 respectively. A graph of the axial stress-strain curve for the laminate is given in Figure 2. Note that the laminate exhibits a non-linear stress-strain behavior from loading onset to failure.

The second sample nonlinear laminate analysis problem is a 0, ± 45 Graphite/Epoxy laminate under combined tension and shear loading. In this case the Ramberg-Osgood parameters were determined by the curve-fit routine from uniaxial stress-strain data supplied as input. The input data and program output listing are given in sections 4.2.2 and 4.2.3 respectively. Output of the program is plotted in the form of axial stress versus axial strain for this case in Figure 3.

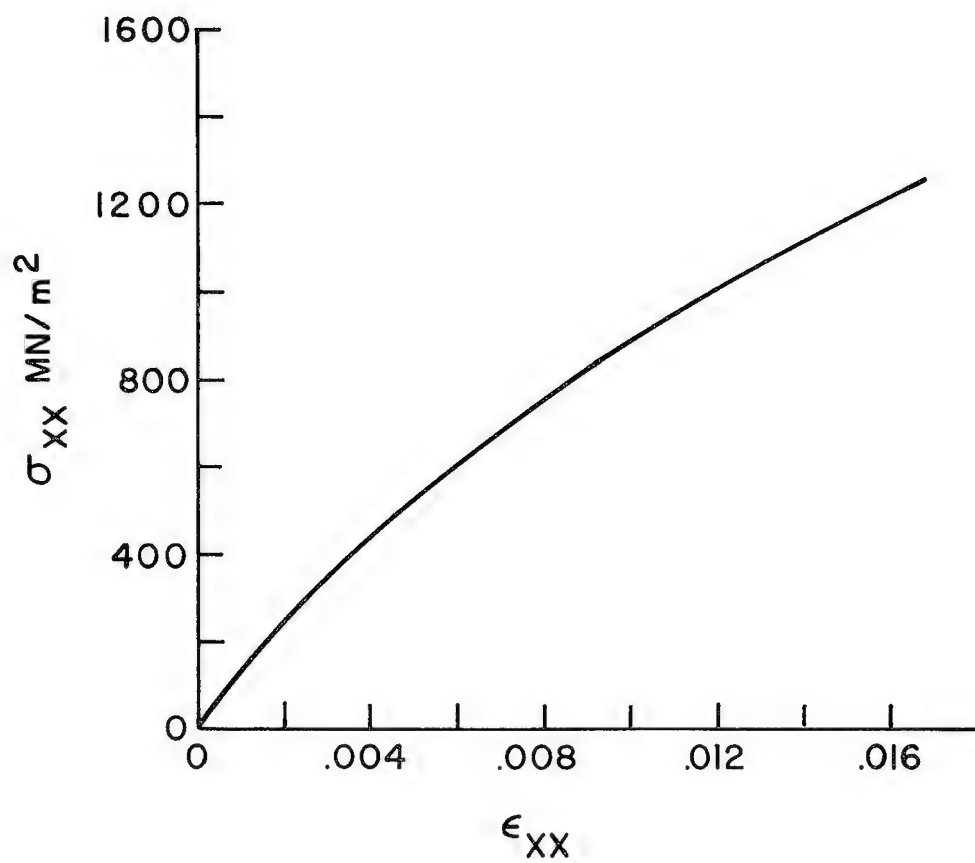


Figure 2 - +30° Boron/Aluminum Laminate - Axial Stress-Strain Behavior.

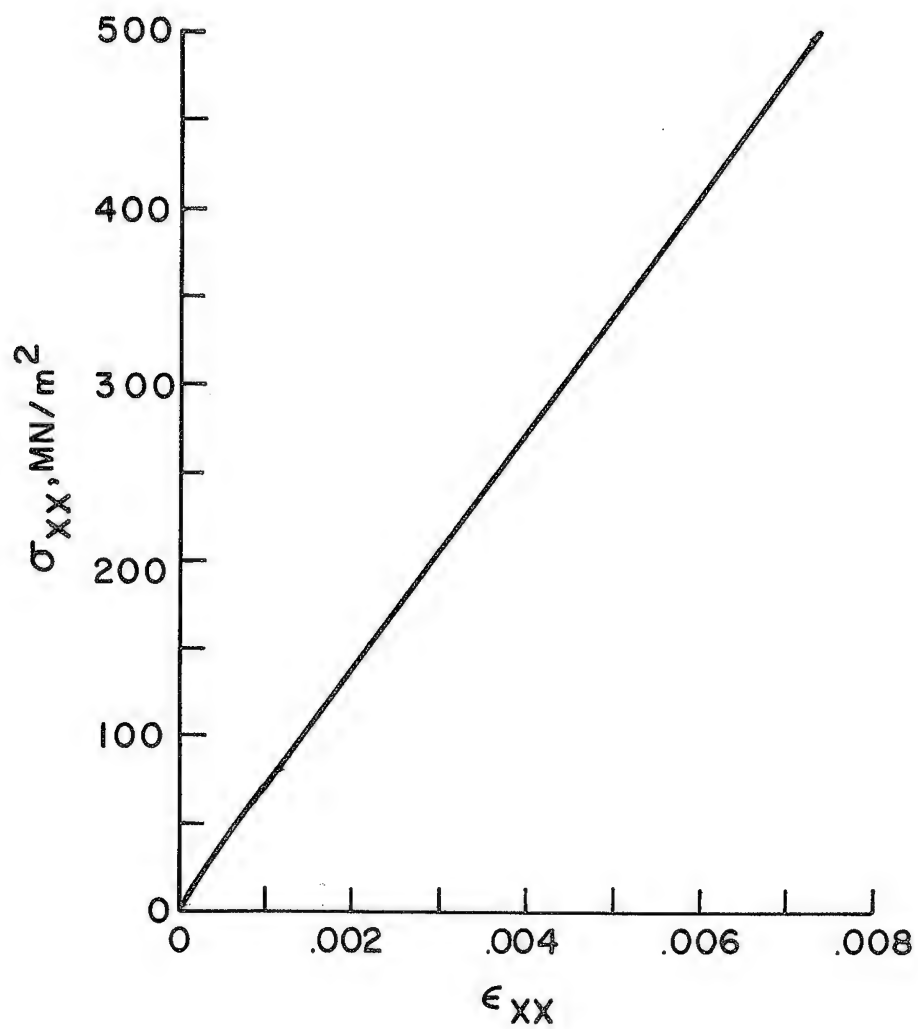


Figure 3 - Axial Stress-Strain Response of [0+45] Graphite-Epoxy Laminate under Axial and Shear Loading.

4.2.2 NOLIN SAMPLE PROBLEM INPUT CARDS

C NOLIN DATA

```

*
*      NOLIN SAMPLE PROBLEMS                      VERS 2 MOD 3
*
*      1.  0,+45,-45 LAMINATE, FULL R-O PARAM CURVE-FIT, ALL FAIL CRIT,
*      2.  +30,-30 LAMINATE, R-O PARAM INPUT, STRAIN FAIL CRIT,
$DATA
NLAY=3,
E11(1)=3*1.982E+05,
E22(1)=3*1.900E+04,
V12(1)=3*0.255E+00,
G12(1)=3*5.770E+03,
THICK(1)=0.25,0.5,0.25,
THETA(1)=45.,0,0,-45.,
IOPT=2,EOPT=1,COPT=1,
IPTS=10,
SIG11(1,1)=6.89E+00,13.78E+00,20.67E+00,27.56E+00,34.45E+00,41.34E+00,
48.23E+00,55.12E+00,62.01E+00,68.90E+00,
EPS11(1,1)=1.1E-03,2.6E-03,4.E-03,5.7E-03,7.6E-03,1.E-02,1.31E-02,
1.65E-02,2.15E-02,2.84E-02,
SIG22(1,1)=6.89E+00,13.78E+00,20.67E+00,27.56E+00,34.45E+00,41.34E+00,
48.23E+00,55.12E+00,62.01E+00,68.90E+00,
EPS22(1,1)=1.1E-03,2.6E-03,4.E-03,5.7E-03,7.6E-03,1.E-02,1.31E-02,
1.65E-02,2.15E-02,2.84E-02,
SIG12(1,1)=6.89E+00,13.78E+00,20.67E+00,27.56E+00,34.45E+00,41.34E+00,

```

NOLIN SAMPLE INPUT CARDS CONT.

```

      48.23E+00,55.12E+00,62.01E+00,68.90E+00,
EPS12(1,1)=2.2E-03,5.2E-03,8.E-03,11.4E-03,15.2E-03,2.E-02,2.62E-02,
3.30E-02,4.30E-02,5.68E-02,
SO11=+5.0E+00,SO22=-2.5E+00,SO12=0.0,
IFCN=4,IPRINT=1,
MATYPE(1)=1,1,1,
S11T(1)=1.32E03,S22T(1)=7.16E+01,S12(1)=1.05E+02,FP11T(1)=6.68E-03,
EP22T(1)=3.77E-03,GAMA(1)=1.827E-02,S11C(1)=2.43E+03,S22C(1)=2.75E+02,
EP11C(1)=1.227E-02,EP22C(1)=1.45E-02,
STIFF=0.100,
A12(1)= 3*-2.8623E-06,
KSGM=50,SMLT=3.0,IT=10,INMT=2%
$DATA
NLAY=2,
E11(1)=2*2.20E+05,
E22(1)=2*1.24E+05,
V12(1)=2*0.01E+00,
G12(1)=2*2.60E+04,
THICK(1)=2*0.50,
THETA(1)=30.0,-30.0,
IOPT=1,
STY(1)=2*1109.E+00,
SCY(1)=2*1467.E+00,
TY(1)=2*93.0E+00,
XM=3.00,XN=3.00,
SO11=50.,
SO22=0.,
SO12=0.,
IFCN=2,
S11T(1)=1100.0,S22T(1)=103.0,S12(1)=93.0,FP11T(1)=0.7E-02,
EP22T(1)=2.0E-02,GAMA(1)=3.0E-02,S11C(1)=1480.0,S22C(1)=160.,
EP11C(1)=0.7E-02,EP22C(1)=0.02,
STIFF=0.100,
KSGM=48,SMLT=4%

```

4.2.3 NOLIN SAMPLE OUTPUT

```

*****
*                                     *
*      NONLINEAR                     *
*      THERMOELASTIC ANALYSTS       *
*      OF                           *
*      FIBROUS COMPOSITES           *
*      AND                           *
*      NON-HOMOGENEOUS LAMINATES    *
*                                     *
*****

```

•VERSION 2 MOD 3 (MAY 74)

•DATE

•PROGRAM IDENTIFICATION

```

*      NOLIN SAMPLE PROBLEMS      VERS 2 MOD 3
*
*      1. 0,45,-45 LAMINATE. FULL R-O PARAM CURVE-FIT. ALL FAIL CRIT.
*      2. +30,-30 LAMINATE. R-O PARAM INPUT. STRAIN FAIL CRIT.

```

32 NUMBER OF LAYERS = 3

DATA INPUT POINTS FOR CURVE FIT

LAYER	THETA	T	E11	E22	V12	V21	G12	SQT Y	SGC Y	TAUY
6.89000E+00 6.20100E+01	1.37800E+01 6.89000E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01			
1.10000E-03 2.15000E-02	2.60000E-03 2.84000E-02	4.00000E-03	5.70000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02			
6.89000E+00 6.20100E+01	1.37800E+01 6.89000E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01			
1.10000E-03 2.15000E-02	2.60000E-03 2.84000E-02	4.00000E-03	5.70000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02			
6.89000E+00 6.20100E+01	1.37800E+01 6.89000E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01			
2.20000E-03 4.30000E-02	5.20000E-03 5.68000E-02	8.00000E-03	1.14000E-02	1.52000E-02	2.00000E-02	2.62000E-02	3.30000E-02			

EQUATION PARAMETERS

EXPONENT M = 2.74596E+00
EXPONENT N = 1.47386E+00

♦♦♦♦♦ EXTERNALLY APPLIED STRESS ♦♦♦♦♦

NO. OF INCREMENTS

SG XX	5.0000E+00	1.5000E+01
SG YY	-2.5000E+00	-7.5000E+00
SG XY	0.	0.

LAMINA FAILURE CRITERIA

ALL FAILURE CRITERIA

LAYER LL TT LT

ULT. STRESS
ULT. STRAIN

NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS

1	TFNS. COMP.	1.32000E+03 2.43000E+03	7.16000E+01 2.75000E+02	1.05000E+02 1.05000E+02
1	TFNS. COMP.	6.68000E-03 1.22700E-02	3.77000E-03 1.45000E-02	1.82700E-02 1.82700E-02
2	TFNS. COMP.	1.32000E+03 2.43000E+03	7.16000E+01 2.75000E+02	1.05000E+02 1.05000E+02
2	TFNS. COMP.	6.68000E-03 1.22700E-02	3.77000E-03 1.45000E-02	1.82700E-02 1.82700E-02
3	TFNS. COMP.	1.32000E+03 2.43000E+03	7.16000E+01 2.75000E+02	1.05000E+02 1.05000E+02
3	TFNS. COMP.	6.68000E-03 1.22700E-02	3.77000E-03 1.45000E-02	1.82700E-02 1.82700E-02

LAYER QUADRATIC INTERACTION TERM (A12)

1	-2.86230E-06
2	-2.86230E-06
3	-2.86230E-06

STIFFNESS = 1.00000E-01

CONTROL PARAMETERS

MAX. NO. OF ITERATIONS = 10
CONVERGENCE CRITERIA = 1.00000E-03
DIVERGENCE CRITERIA = 2.00000E+04

LAMINATE CONSTANTS (STRESS-STRAIN)

EXX = 1.11891E+05
EYY = 3.49664E+04
VYX = 6.85439E-01
VXY = 2.14203E-01
GXY = 2.89865E+04

APPLIED STRESS ANALYSIS *****

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+00
SG YY = -2.50000E+00
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-4.44278E+00	-4.36713E-01	-9.62175E-01	6.18445E-05	-1.15643E-04	-7.23315E-13	-2.68992E-05	-2.68992E-05	-8.87437E-09
2	1.19776E+01	-1.09807E+00	0.	6.18445E-05	-1.15643E-04	0.	6.18445E-05	-1.15643E-04	0.
3	-5.44278E+00	-4.36713E-01	9.62182E-01	6.18452E-05	-1.15644E-04	-7.41279E-13	-2.68992E-05	-2.68992E-05	8.87444E-05

EXTERNAL APPLIED STRESS

SG XX = 2.00000E+01
SG YY = -1.00000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 3 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-2.54934E+01	-1.60973E+00	-2.74989E+00	2.61075E-04	-5.14182E-04	2.48289E-11	-1.26554E-04	-1.26554E-04	-3.87628E-04
2	5.08018E+01	-3.69865E+00	0.	2.61075E-04	-5.14182E-04	0.	2.61075E-04	-5.14182E-04	0.
3	-2.54934E+01	-1.60973E+00	2.74964E+00	2.61039E-04	-5.14147E-04	2.45162E-11	-1.26554E-04	-1.26554E-04	3.87593E-04

EXTERNAL APPLIED STRESS

SG XX = 3.50000E+01
SG YY = -1.75000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 4 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-4.87608E+01	-2.72727E+00	-3.22333E+00	4.74559E-04	-9.59587E-04	-2.64055E-12	-2.42514E-04	-2.42514E-04	-7.17073E-04
2	9.25187E+01	-6.03463E+00	0.	4.74559E-04	-9.59587E-04	0.	4.74559E-04	-9.59587E-04	0.
3	-4.87608E+01	-2.72727E+00	3.22336E+00	4.74565E-04	-9.59594E-04	-2.64345E-12	-2.42514E-04	-2.42514E-04	7.17080E-04

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+01

SG YY = -2.50000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 3 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.13712E+01	-3.76005E+00	-3.24699E+00	6.93289E-04	-1.42397E-03	-3.78710E-12	-3.65339E-04	-3.65339E-04	-1.05863E-03
2	1.15323E+02	-8.18288E+00	0.	6.93289E-04	-1.42397E-03	0.	6.93289E-04	-1.42397E-03	0.
3	-7.13712E+01	-3.76005E+00	3.24699E+00	6.93302E-04	-1.42398E-03	-3.79320E-12	-3.65339E-04	-3.65339E-04	1.05864E-03

EXTERNAL APPLIED STRESS

SG XX = 6.50000E+01
SG YY = -3.25000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-0.45741E+01	-4.75320E+00	-3.15385E+00	9.13755E-04	-1.89622E-03	-2.15423E-12	-4.91231E-04	-4.91231E-04	-1.40499E-03
2	1.78510E+02	-1.01825E+01	0.	9.13755E-04	-1.89622E-03	0.	9.13755E-04	-1.89622E-03	0.
3	-0.45741E+01	-4.75320E+00	3.15387E+00	9.13745E-04	-1.89623E-03	-2.15636E-12	-4.91231E-04	-4.91231E-04	1.40500E-03

EXTERNAL APPLIED STRESS

SG XX = 8.00000E+01
SG YY = -4.00000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-1.24105E+02	-5.68706E+00	-3.03740E+00	1.13489E-03	-2.37258E-03	3.92971E-12	-6.18844E-04	-6.18844E-04	-1.75374E-03
2	2.21859E+02	-1.20665E+01	0.	1.13489E-03	-2.37258E-03	0.	1.13489E-03	-2.37258E-03	0.
3	-1.24105E+02	-5.68706E+00	3.03736E+00	1.13487E-03	-2.37256E-03	3.92203E-12	-6.18844E-04	-6.18844E-04	1.75372E-03

EXTERNAL APPLIED STRESS

SG XX = 9.50000E+01
SG YY = -4.75000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

ETC.

36.

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.09459E+02	-2.12599E+01	-1.91901E+00	6.02590E-03	-1.31302E-02	2.76845E-12	-3.55216E-03	-3.55216E-03	-9.57806E-03
2	1.18344E+03	-4.27218E+01	0.	6.02590E-03	-1.31302E-02	0.	6.02590E-03	-1.31302E-02	0.
3	-7.09459E+02	-2.12599E+01	1.91900E+00	6.02590E-03	-1.31302E-02	2.75785E-12	-3.55216E-03	-3.55216E-03	9.57801E-03

EXTERNAL APPLIED STRESS

SG XX = 4.25000E+02
 SG YY = -2.12500E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.36579E+02	-2.18573E+01	-1.89844E+00	6.24879E-03	-1.36252E-02	2.50081E-12	-3.68822E-03	-3.68822E-03	-9.93701E-03
2	1.2732E+03	-4.38833E+01	0.	6.24879E-03	-1.36252E-02	0.	6.24879E-03	-1.36252E-02	0.
3	-7.36579E+02	-2.18573E+01	1.89843E+00	6.24879E-03	-1.36252E-02	2.49188E-12	-3.68822E-03	-3.68822E-03	9.93696E-03

EXTERNAL APPLIED STRESS

SG XX = 4.40000E+02
 SG YY = -2.20000E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.43727E+02	-2.24492E+01	-1.87882E+00	6.47171E-03	-1.41206E-02	2.26652E-12	-3.82443E-03	-3.82443E-03	-1.02961E-02
2	1.27121E+03	-4.50331E+01	0.	6.47171E-03	-1.41206E-02	0.	6.47171E-03	-1.41206E-02	0.
3	-7.43727E+02	-2.24492E+01	1.87881E+00	6.47166E-03	-1.41205E-02	2.25905E-12	-3.82443E-03	-3.82443E-03	1.02961E-02

LAMINATE HAS FAILED+ EP 11 EXCEEDS MAXIMUM

AT FIRST POST-FAILURE LOAD POINT

EXTERNAL APPLIED STRESS

SG XX = 4.55000E+02
 SG YY = -2.27500E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS

STRAIN

STRAIN

LAYER	(LAYER AXES)			(LAMINATE AXES)			(LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.40900E+02	-2.34735E+01	-1.86008E+00	6.69466E-03	-1.46162E-02	2.06077E-12	-3.96078E-03	-3.96078E-03	-1.06554E-02
2	1.31511E+03	-4.61719E+01	0.	6.69466E-03	-1.46162E-02	0.	6.69466E-03	-1.46162E-02	0.
3	-7.40900E+02	-2.34735E+01	1.86007E+00	6.69466E-03	-1.46162E-02	2.05438E-12	-3.96078E-03	-3.96078E-03	1.06554E-02

*** LAMINATE ANALYSIS INTERPOLATED TO FAILURE POINT ***

AT FAILURE
EXTERNAL APPLIED STRESS

SG XX = 4.54014E+02
SG YY = -2.27007E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.49113E+02	-2.29972E+01	-1.86128E+00	6.68000E-03	-1.45836E-02	1.07969E-13	-3.95181E-03	-3.95181E-03	-1.06318E-02
2	1.31222E+03	-4.61974E+01	0.	6.68000E-03	-1.45836E-02	0.	6.68000E-03	-1.45836E-02	0.
3	-7.49113E+02	-2.29972E+01	1.86128E+00	6.68000E-03	-1.45836E-02	1.07941E-13	-3.95181E-03	-3.95181E-03	1.06318E-02

LAMINATE HAS FAILED+ SG 11 EXCEEDS MAXIMUM

AT FIRST POST-FAILURE LOAD POINT
EXTERNAL APPLIED STRESS

SG XX = 4.70000E+02
SG YY = -2.35000E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.18099E+02	-2.36168E+01	-1.84215E+00	6.91764E-03	-1.51122E-02	1.87914E-12	-4.09726E-03	-4.09726E-03	-1.10149E-02
2	1.45902E+03	-4.73000E+01	0.	6.91764E-03	-1.51122E-02	0.	6.91764E-03	-1.51122E-02	0.
3	-8.18099E+02	-2.36168E+01	1.84215E+00	6.91764E-03	-1.51121E-02	1.87378E-12	-4.09726E-03	-4.09726E-03	1.10149E-02

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AT FAILURE
EXTERNAL APPLIED STRESS

SG XX = 4.56671E+02
SG YY = -2.28336E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.93930E+02	-2.31006E+01	-1.85804E+00	6.71947E-03	-1.46715E-02	1.96310E-12	-3.97598E-03	-3.97598E-03	-1.06955E-02
2	1.82009E+03	-4.62981E+01	0.	6.71950E-03	-1.46715E-02	0.	6.71950E-03	-1.46715E-02	0.
3	-7.93930E+02	-2.31006E+01	1.85803E+00	6.71947E-03	-1.46715E-02	1.95735E-12	-3.97598E-03	-3.97598E-03	1.06955E-02

EXTERNAL APPLIED STRESS

SG XX = 4.85000E+02
SG YY = -2.42500E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-R.45321E+02	-2.41931E+01	-1.82498E+00	7.14066E-03	-1.56084E-02	1.71832E-12	-4.23386E-03	-4.23386E-03	-1.13745E-02
2	1.40293E+03	-4.84179E+01	0.	7.14066E-03	-1.56084E-02	0.	7.14066E-03	-1.56084E-02	0.
3	-R.45321E+02	-2.41931E+01	1.82498E+00	7.14062E-03	-1.56084E-02	1.71377E-12	-4.23386E-03	-4.23386E-03	1.13745E-02

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+02
SG YY = -2.50000E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-R.72567E+02	-2.47445E+01	-1.80852E+00	7.36370E-03	-1.61049E-02	1.57546E-12	-4.37059E-03	-4.37059E-03	-1.17343E-02
2	1.44686E+03	-4.95259E+01	0.	7.36370E-03	-1.61049E-02	0.	7.36370E-03	-1.61049E-02	0.
3	-R.72567E+02	-2.47445E+01	1.80851E+00	7.36347E-03	-1.61049E-02	1.57158E-12	-4.37059E-03	-4.37059E-03	1.17343E-02

LAMINATE HAS FAILED QUADRATIC INTERACTION FAILURE 2
 QUADRATIC = 1.0320 FOR LAYER 2
 QUADRATIC = .9714 FOR LAYER 2 OF PREVIOUS LOAD

AT FIRST POST-FAILURE LOAD POINT
 EXTERNAL APPLIED STRESS

SG XX = 5.15000E+02
 SG YY = -2.57500E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.99834E+02	-2.53313E+01	-1.79271E+00	7.58678E-03	-1.66017E-02	1.44798E-12	-4.50744E-03	-4.50744E-03	-1.20942E-02
2	1.49079E+03	-5.06244E+01	0.	7.58678E-03	-1.66017E-02	0.	7.58678E-03	-1.66017E-02	0.
3	-8.99834E+02	-2.53313E+01	1.79270E+00	7.58675E-03	-1.66016E-02	1.44462E-12	-4.50744E-03	-4.50744E-03	1.20942E-02

*** LAMINATE ANALYSIS INTERPOLATED TO FAILURE POINT ***

AT FAILURE
 EXTERNAL APPLIED STRESS

SG XX = 5.07082E+02
 SG YY = -2.53541E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.95438E+02	-2.50327E+01	-1.80097E+00	7.46902E-03	-1.63394E-02	7.18620E-13	-4.43519E-03	-4.43519E-03	-1.19042E-02
2	1.46760E+03	-5.01457E+01	0.	7.46902E-03	-1.63394E-02	0.	7.46902E-03	-1.63394E-02	0.
3	-8.95438E+02	-2.50327E+01	1.80097E+00	7.46900E-03	-1.63394E-02	7.17842E-13	-4.43519E-03	-4.43519E-03	1.19042E-02

NUMBER OF LAYERS = 2

LAYER	THETA	T	E11	E22	V12	V21	012	SGT Y	SGC Y	TAUY
1	30.00	5.0000E-01	2.2000E+05	1.2400E+05	1.0000E-02	5.6304E-03	2.6000E+04	1.1090E+03	1.4670E+03	9.3000E+01
2	-30.00	5.0000E-01	2.2000E+05	1.2400E+05	1.0000E-02	5.6304E-03	2.6000E+04	1.1090E+03	1.4670E+03	9.3000E+01

EQUATION PARAMETERS

EXPONENT M = 3.00000E+00
EXPONENT N = 3.00000E+00

EXTERNALLY APPLIED STRESS

INITIAL STRESS	STRESS INCREMENT	NO. OF INCREMENTS
SG XX 5.00000E+01	2.00000E+02	48
SG YY 0.	0.	
SG XY 0.	0.	

LAMINA FAILURE CRITERIA

LAYER	LL	TT	LT
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NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS

1	TENS. 7.00000E-03	2.00000E-02	3.00000E-02
	COMP. 7.00000E-03	2.00000E-02	3.00000E-02
2	TENS. 7.00000E-03	2.00000E-02	3.00000E-02
	COMP. 7.00000E-03	2.00000E-02	3.00000E-02

STIFFNESS = 1.00000E-01

CONTROL PARAMETERS

MAX. NO. OF ITERATIONS = 10
CONVERGENCE CRITERIA = 1.00000E-03
DIVERGENCE CRITERIA = 2.00000E+04

LAMINATE CONSTANTS (STRESS-STRAIN)

EXX = 1.31218E+05
EYY = 8.96347E+04

VYX	=	4.42435E-01
VXY	=	3.02224E-01
GXY	=	7.05386E+04

APPLIED STRESS ANALYSIS

EXTERNAL APPLIED STRESS

SG XX = 5.0000E+01
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	5.37302E+01	-3.73016E+00	-1.22801E+01	3.83121E-04	-1.71772E-04	-2.68684E-13	2.44398E-04	-3.3049E-05	-2.40276E-04
2	5.37302E+01	-3.73016E+00	1.22801E+01	3.83121E-04	-1.71772E-04	-1.88746E-13	2.44398E-04	-3.3049E-05	2.40276E-04

EXTERNAL APPLIED STRESS

SG XX = 2.5000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	2.90731E+02	-3.07312E+01	-5.44261E+01	2.08896E-03	-1.15710E-03	-8.72517E-10	1.27745E-03	-3.45581E-04	-1.40559E-03
2	2.90731E+02	-3.07312E+01	5.44261E+01	2.08896E-03	-1.15710E-03	-6.85787E-10	1.27745E-03	-3.45581E-04	1.40559E-03

EXTERNAL APPLIED STRESS

SG XX = 4.5000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	5.25892E+02	-7.58473E+01	-8.61013E+01	4.17189E-03	-2.93967E-03	-3.02218E-07	2.39387E-03	-1.10165E-03	-3.07947E-03
2	5.25892E+02	-7.58473E+01	8.60956E+01	4.17132E-03	-2.93967E-03	-2.85248E-07	2.39370E-03	-1.10204E-03	3.07909E-03

EXTERNAL APPLIED STRESS

SG XX = 6.5000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	7.40039E+02	-1.30051E+02	-1.12556E+02	6.64157E-03	-5.71879E-03	1.41357E-07	3.55154E-03	-2.62876E-03	-5.35216E-03
2	7.40052E+02	-1.30040E+02	1.12556E+02	6.64179E-03	-5.71877E-03	1.19534E-07	3.55160E-03	-2.62868E-03	5.35231E-03

EXTERNAL APPLIED STRESS

SG XX = 8.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	1.03875E+03	-1.44653E+02	-1.36434E+02	9.53050E-03	-9.66849E-03	-1.48380E-06	4.74018E-03	-4.86807E-03	-8.31382E-03
2	1.03866E+03	-1.44747E+02	1.36422E+02	9.52838E-03	-9.66863E-03	-1.31694E-06	4.72970E-03	-4.86905E-03	8.31222E-03

EXTERNAL APPLIED STRESS

SG XX = 1.05000E+03
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	1.29984E+03	-2.49716E+02	-1.58908E+02	1.28870E-02	-1.49782E-02	-2.27314E-06	5.91972E-03	-8.01090E-03	-1.20665E-02
2	1.29971E+03	-2.49833E+02	1.58895E+02	1.28838E-02	-1.49784E-02	-1.99637E-06	5.91912E-03	-8.01372E-03	1.20642E-02

LAMINATE HAS FAILED EP 11 EXCEEDS MAXIMUM

AT FIRST POST-FAILURE LOAD POINT

EXTERNAL APPLIED STRESS

SG XX = 1.25000E+03
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS			STRAIN		
--------	--	--	--------	--	--

LAYER	(LAYER AXES)		(LAMINATE AXES)			(LAYER AXES)			
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	1.56228E+03	-3.12157E+02	-1.80593E+02	1.67730E-02	-2.18526E-02	-2.67009E-06	7.11545E-03	-1.21950E-02	-1.67260E-02
2	1.56215E+03	-3.12271E+02	1.80581E+02	1.67695E-02	-2.18529E-02	-2.32925E-06	7.11488E-03	-1.21983E-02	1.67234E-02

***** PROGRAM TERMINATED *****

5. Computer Program Listings

Source listings of both the UNI and NOLIN computer programs follow. The UNI program requires 20 K of computer core storage in a CDC 6600 machine, while the NOLIN program requires 60 K of core storage. No peripheral devices are required for either program for intermediate data storage.


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000003 C GF(J) ! SHEAR MODULUS FOR JTH FIBER
000003 C GM(J) ! SHEAR MODULUS FOR JTH MATRIX
000003 C AKF(J) ! PLANE STRAIN BULK MODULUS FOR JTH FIBER
000003 C AKM(J) ! PLANE STRAIN BULK MODULUS FOR JTH MATRIX
000003 C
000003 C EFFECTIVE THERMOELASTIC PARAMETERS
000003 C AKTS(J) ! EFFECTIVE TRANS. BULK MOD. FOR JTH MATERIAL
000003 C EAS(J) ! EFFECTIVE AXIAL YOUNG'S MOD. FOR JTH MATERIAL
000003 C ETS(J) ! EFFECTIVE TRANS. YOUNG'S MOD. FOR JTH MATERIAL
000003 C ANUAS(J) ! EFF. POISSON RATIO (UNIDIRECTIONAL AX. STRESS) FOR JTH MATERIAL
000003 C ANUTS(J) ! EFF. POISSON RATIO (IN TRANSVERSE PLANE) FOR JTH MATERIAL
000003 C GAS(J) ! EFF. SHEAR MOD. (IN FIBER PLANES) FOR JTH MATERIAL
000003 C GTS(J) ! EFF. SHEAR MOD. (IN TRANS. PLANES) FOR JTH MATERIAL
000003 C ALPAS(J) ! EFF. (FIBER DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
000003 C ALPTS(J) ! EFF. (TRANS. DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
000003 C RHOS(J) ! BULK DENSITY FOR JTH MATERIAL
000003 C RCOMP(J) ! RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR JTH MATERIAL
000003 C
000003 C * PROGRAMMING INFORMATION *
000003 C
000003 C UNI MAY BE USED AS A SUBROUTINE
000003 C SUBROUTINES REQUIRED ! MSUB01,MSUB02
000003 C
000003 C *****
000003 C INITIALIZE VARIABLES TO ZERO.
000003 C NAMELIST/DATAONE/NF,NM,NVM,EF,ANUF,RHOF,EFA,ANUFA,GFA,EFT,ANUFT,
000003 C IEM,ANUM,RHOM,VN,ROMS,ALPF,ALPFT,ALPM
000003 C DATA EFT/20*0.0/
000003 C DATA ROMS/20*0.0/
000003 C DATA ALPM/20*0.0/
000003 C
000003 C 171 CONTINUE
000003 C READ(5,DATAONE)
000003 C IF(EOF,5)172,173
000003 C 173 CONTINUE
000003 C IF(EFT(1))1012,1012,1014
000003 C 1012 CONTINUE
000003 C DO 3 J=1,NF
000003 C IF (J.NE.1) GO TO 4
000003 C WRITE(6,202)
000003 C IF(ALPM(1))5,5,6
000003 C 5 WRITE(6,203)
000003 C GO TO 4
000003 C 6 WRITE(6,204)
000003 C 4 GF(J) = EF(J)/(1.0+ANUF(J))*2.0)
000003 C AKF(J) = GF(J)/(1.0-2.0*ANUF(J))
000003 C IF(ALPM(1))8,8,9
000003 C 8 WRITE(6,205) (J,EF(J),ANUF(J),GF(J),AKF(J),RHOF(J))
000003 C GO TO 3
000003 C 9 WRITE(6,206) (J,EF(J),ANUF(J),GF(J),AKF(J),RHOF(J),ALPF(J))
000003 C 3 CONTINUE
000003 C GO TO 1018
000003 C 1014 CONTINUE
000003 C DO 503 J=1,NF
000003 C IF (J.NE.1) GO TO 504

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00018600
00018700

00018900
00019000
00019100
00019200
00019300

00019500
00019600
00019700
00019800

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000122 IF (ALPM(1)) 505, 505, 506
000123 505 WRITE(6, 203)
000127 GO TO 504
000130 506 WRITE(6, 204)
000134 504 CONTINUE
000134 GFT(J) = EFT(J) / ((1.0 + ANUFT(J)) * 2.0)
000141 AKF(J) = EFA(J) * EFT(J) / (2. * EFA(J) * (1. - ANUFT(J)) - 6. * EFT(J) *
1 ANUFA(J) * 2)
000154 IF (ALPM(1)) 508, 508, 509
000155 508 WRITE(6, 205) (J, EFA(J), ANUFA(J), GFA(J), AKF(J), RHOF(J))
000175 WRITE(6, 205) (J, EFT(J), ANUFT(J), GFT(J), AKF(J), RHOF(J))
000215 GO TO 503
000216 509 WRITE(6, 206) (J, EFA(J), ANUFA(J), GFA(J), AKF(J), RHOF(J), ALPF(J))
000240 WRITE(6, 206) (J, EFT(J), ANUFT(J), GFT(J), AKF(J), RHOF(J), ALPFT(J))
000262 503 CONTINUE
000265 1018 CONTINUE
000265 DO 10 J = 1, NM
000267 IF (J.NF.1) GO TO 11
000271 IF (ALPM(1)) 12, 12, 13
000272 12 WRITE(6, 207)
000276 GO TO 11
000277 13 WRITE(6, 208)
000303 11 GM(J) = EM(J) / ((1.0 + ANUM(J)) * 2.0)
000310 AKM(J) = GM(J) / (1.0 - 2.0 * ANUM(J))
000314 IF (ALPM(1)) 14, 14, 15
000315 14 WRITE(6, 205) (J, EM(J), ANUM(J), GM(J), AKM(J), RHOM(J))
000335 GO TO 10
000336 15 WRITE(6, 206) (J, EM(J), ANUM(J), GM(J), AKM(J), RHOM(J), ALPM(J))
000360 10 CONTINUE
C
000363 IF (ROMS(1), .EQ. 0) GO TO 777
000364 WRITE (6, 217)
000367 DO 779 J=1, NM
C
C CALCULATE THE EFFECTIVE THERMO-ELASTIC PARAMETERS
C
779 WRITE (6, 216) J, ROMS(J)
777 KLINE = 49
L = 0
DO 100 I=1, NF
C FORM FIBER COMPLIANCE MATRIX
IF (ALPM(1)) 910, 910, 911
911 IF (EFT(1), .EQ. 0) CALL MSUB01(I, EF, EF, ANUF, ANUF, SF)
IF (EFT(1), .NE. 0) CALL MSUB01(I, EFA, EFT, ANUFA, ANUFT, SF)
910 CONTINUE
C
DO 100 J=1, NM
C FORM MATRIX COMPLIANCE MATRIX
IF (ALPM(1)) 912, 912, 913
913 CALL MSUB01(J, EM, EM, ANUM, ANUM, SM)
912 CONTINUE
DO 100 K=1, NVM
L = L + 1
MM(L) = J
MF(L) = I
MV(L) = K
VF = 1.0 - VM(K)
000441
000441
00019900
00020000
00020200
00020300
00020400
00020500
00020600
00020800
00021000
00021100
00021300
00021400
00021600
00021700
00021800
00021900
00022000
00022100

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```

000443 RCOMP(L)=ROMS(J)*SORT(3.*(1.+VF)**3/(3.*13.*VF+VF**2+VF**3))
000463 P1 = VM(K)*AKM(J)*(AKF(I)+GM(J))+VF*AKF(I)*(AKM(J)+GM(J))
000474 Q1 = VM(K)*(AKF(I)+GM(J))+VF*(AKM(J)+GM(J))
000505 AKTS(L) = P1/Q1
000510 IF(LEFT(1))1022,1022,1026
000511 1022 CONTINUE
000511 P2 = 4.0*(ANUF(I)-ANUM(J))*(ANUF(I)-ANUM(J))*VF*VM(K)
000511 Q2 = VM(K)/AKF(I)+VF/AKM(J)+1.0/GM(J)
000520 EAS(L) = VF*EF(I)+VM(K)*EM(J)+P2/Q2
000527 P3 = VF*VM(K)*(ANUF(I)-ANUM(J))*(1.0/AKM(J)-1.0/AKF(I))
000537 Q3 = Q2
000551 ANUAS(L) = VF*ANUF(I)+VM(K)*ANUM(J)+P3/Q3
000553 P4 = VM(K)*GM(J)+(1.0+VF)*GF(I)
000562 Q4 = (1.0+VF)*GM(J)+VM(K)*GF(I)
000571 GAS(L) = GM(J)*P4/Q4
000577 GAMMA = GF(I)/GM(J)
000603 RETAM = 1.0/(3.0-4.0*ANUM(J))
000605 RETAF = 1.0/(3.0-4.0*ANUF(I))
000611 GO TO 1028
000616 1026 CONTINUE
000616 P2 = 4.0*(ANUFA(I)-ANUM(J))*(ANUFA(I)-ANUM(J))*VF*VM(K)
000616 Q2 = VM(K)/AKF(I)+VF/AKM(J)+1.0/GM(J)
000625 EAS(L) = VF*EFA(I)+VM(K)*EM(J)+P2/Q2
000634 P3 = VF*VM(K)*(ANUFA(I)-ANUM(J))*(1.0/AKM(J)-1.0/AKF(I))
000644 Q3 = Q2
000656 ANUAS(L) = VF*ANUFA(I)+VM(K)*ANUM(J)+P3/Q3
000660 P4 = VM(K)*GM(J)+(1.0+VF)*GFA(I)
000667 Q4 = (1.0+VF)*GM(J)+VM(K)*GFA(I)
000676 GAS(L) = GM(J)*P4/Q4
000704 GAMMA = GF(I)/GM(J)
000710 RETAM = 1.0/(3.0-4.0*ANUM(J))
000712 RETAF = 1.0/(1.0 + (2.0*GFT(I))/AKF(I))
000716 1028 CONTINUE
000723 ALEF = 1.E50
000723 IF(GAMMA.NE.1.0) ALEF = (GAMMA*RETAM)/(GAMMA-1.0)
000725 RP = GAMMA*BETAF
000733 R = (BETAM-RP)/(1.0+RP)
000735 VF3 = VF*VF*VF
000741 VM2 = VM(K)*VM(K)
000742 RETAM2 = RETAM*RETAM
000744 X1 = 1.0+P*VF3
000746 X2 = 3.0*VF*VM2*BETAM2
000751 P5 = (ALEF+BETAM*VF)*X1-X2
000754 Q5 = (ALEF-VF)*X1-X2
000761 IF(GAMMA.EQ.1.0) GTS(L)=GM(J)
000763 IF(GAMMA.NE.1.0) GTS(L)=GM(J)*P5/Q5
000770 P6 = 4.0*AKTS(L)*GTS(L)
000776 Q6 = AKTS(L)+(1.0+4.0*AKTS(L)*ANUAS(L)*ANUAS(L)/EAS(L))*GTS(L)
001001 ETS(L) = P6/Q6
001012 ANUTS(L) = 0.5*(ETS(L)/GTS(L))-1.0
001014 IF(ALPM(1))20,20,920
001020 920 IF(LEFT(1).NE.0)GO TO 921
001021 BIGKM(J) = EM(J)/(3.0*(1.0-2.0*ANUM(J)))
001022 RIGKF(I) = EF(I)/(3.0*(1.0-2.0*ANUF(I)))
001030 BARRK = VM(K)/RIGKM(J)+VF/BIGKF(I)
001035

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001042 ALBAR = VF*ALPFF(I)+VM(K)*ALPM(J)
001046 F1 = 0.0
001047 IF (BIGKM(J).NE.BIGKF(I)) F1 = (ALPM(J)-ALPFF(I))/
1 (1.0/BIGKM(J)-1.0/BIGKF(I))
001061 F2 = (3.0*(1.0 - 2.0* ANUAS(L)))/EAS(L)
001067 ALPHA(1,L) = ALBAR + F1*(F2 - BARRK)
001074 ALPHA(2,L) = ALBAR + F1*(F2 - BARRK)
001106 GO TO 20
001106 921 CONTINUE

C
C FORM COMPOSITE COMPLIANCE MATRIX AND CALCULATE MATERIAL THERMAL
C EXPANSION COEFFICIENTS
C CALL MSUR02(I,J,K,VF,SF,SM)
20 RHOS(L) = VM(K)*RHOM(J)+VF*RHOF(I)
KLINE = KLINE+3
IF (KLINE.LE.48) GO TO 22
KLINE = 0
WRITE(6,215)
IF (ALPM(I)) 23,23,24
23 WRITE(6,209)
GO TO 22
24 WRITE(6,210)
22 IF (ALPM(I)) 25,25,26
25 WRITE(6,211) I,J,L,VM(K),EAS(L),ANUAS(L),GAS(L),AKTS(L)
WRITE(6,212) ETS(L),ANUTS(L),GTS(L),RHOS(L)
GO TO 778
26 WRITE(6,213) I,J,L,VM(K),EAS(L),ANUAS(L),GAS(L),AKTS(L),ALPHA(1,L)
WRITE(6,214) ETS(L),ANUTS(L),GTS(L),RHOS(L),ALPHA(2,L)
778 IF (RONS.NE.0) WRITE(6,218) RCOMP(L)
100 CONTINUE
C

001273 GO TO 171
001273 172 WRITE(6,1999)
001277 STOP
001301 200 FORMAT(1R14)
001301 201 FORMAT(1P6E12.5)
001301 202 FORMAT(1H1///42X37HCONSTITUENT THERMO-ELASTIC PARAMETERS)
001301 203 FORMAT(///11H FIBER NO.,11X4HE(F),12X5HNU(F),11X4HG(F),12X4HK(F),
11X6HRHO(F),//)
001301 204 FORMAT(///11H FIBER NO.,11X4HE(F),12X5HNU(F),11X4HG(F),12X4HK(F),
11X6HRHO(F),9X8HALPHA(F)//)
001301 205 FORMAT(17,7X,5G16.5)
001301 206 FORMAT(17,7X,6G16.5)
001301 207 FORMAT(///12H MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M),
11X4HK(M),11X6HRHO(M),//)
001301 208 FORMAT(///12H MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M),
11X4HK(M),11X6HRHO(M),9X8HALPHA(M)//)
001301 209 FORMAT(///31HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*,10X6HNU(A)*,
11X5HG(A)*,11X5HK(T)*,42X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,
21X4HRHO*)
001301 210 FORMAT(///31HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*,
11X6HNU(A)*,11X5HG(A)*, 11X5HK(T)*,9X9HALPHA(A)*,
24X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,11X4HRHO*,10X9HALPHA(T)*,
211 FORMAT(214,17,615.5,4X,4G14.5)
001301 212 FORMAT(34X,4G14.5)

```

00025600

00025800

00025900

00026000

00026100

00026200

00026300

00026400

00026500

00026700

00026800

00026900

00027100

00027200

00027400

00027500

00027600

00015000

00015100

00015200

00015300

00015400

00015500

00015600

00015700

00015800

00015900

00016000

00016100

00016200

00016300

00016400

00016500

00016600

00016700

00016800

00016900

00017000

00017100

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```
001301 213 FORMAT(/2I4,I7,G15.5,4X,5G16.5)
001301 214 FORMAT(34X,5G16.5)
001301 215 FORMAT(1H1///42X35HEFFECTIVE THERMO-ELASTIC PARAMETERS)
001301 216 FORMAT(17,7X,G16.5)
001301 217 FORMAT(///12H MATRIX NO.,8X,8H R=0-S(M)///)
001301 218 FORMAT(//,38X,16H R=0 PARAMETER =,1E16.5)
001301 1999 FORMAT(///***** PROGRAM TERMINATED *****)
001301 1*****
C      END
001301 00028100
```

00017200
00017300
00017400

52


```

C SUBROUTINES
C : LAMTST,OUTPT1,PROP,REGAI,QUADCF,INVRTD,CHAI,
C : CONVR,HEADER,ANGLE,MMULD,TRANS,RESET,NRIRM,
C : MATCPL,LAYSUR
C : SINT
C : INITIALIZE VARIABLES IN COMMON SETS
C : 01.05,10.11, AND 14
C
C * LIMITATIONS *
C
C * DEFAULT VALUES *
C
C EPS = 1.00E-03
C UPBD = 2.00E+04
C IT = 100
C AL2(I) = 0.00 (FOR ALL LAYERS)
C XM = 3.00E 00
C XN = 3.00E 00
C INMT = 2
C
C * INPUT PARAMETERS *
C
C NST : NO. OF SEPERATE LAMINATES
C IOPT : INPUT OPTION
C      #1: INPUT RAMBERG-OZGOOD PARAMETERS TY,STY,SCY,XM,XN
C      #2: DETERMINE RAMBERG-OZGOOD PARAMETERS FROM CURVE-FIT
C      #3: EXPONENT OPTION FOR CURVE-FIT ROUTINE
C      #4: CURVE-FIT FOR ALL RAMBERG-OZGOOD PARAMETERS
C      #5: INPUT EXPONENTS, XM + XN, CURVE-FIT TY,STY,SLY
C      #6: LAYER OPTION FOR CURVE-FIT ROUTINE
C      #7: USE SAME STRESS-STRAIN DATA FOR ALL LAYERS
C      #8: STRESS-STRAIN DATA INPUT FOR EACH LAYER
C
C LAMINATE PROPERTIES
C LAY : NO. OF LAYERS IN LAMINATE
C E11(I) : AXIAL YOUNG'S MODULUS (LAYER I)
C E22(I) : TRANSVERSE YOUNG'S MODULUS (LAYER I)
C V12(I) : AXIAL-TRANSVERSE POISSON RATIO (LAYER I)
C G12(I) : IN-PLANE SHEAR MODULUS (LAYER I)
C IANG(I) : ANGULAR ORIENTATION (DEGREES) OF ITH LAYER
C T(I) : THICKNESS OF ITH LAYER
C
C CURVE-FIT PARAMETERS
C IPTS : NO. OF DATA POINTS
C STRS(I) : ITH STRESS DATA POINT
C STRN(I) : ITH STRAIN DATA POINT
C
C POINTS --- COMPONENT
C 1 - SIGMA 11
C 2 - EPSILON 11
C 3 - SIGMA 22
C 4 - EPSILON 22
C 5 - SIGMA 12
C 6 - EPSILON 12

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MAIN

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C   LOADING PARAMETERS
C   S011 : AXIAL APPLIED LOAD
C   S022 : TRANSVERSE APPLIED LOAD
C   S012 : APPLIED SHEAR
C   IFCN : FAILURE OPTION
C       =1: ULTIMATE STRESS
C       =2: QUADRATIC INTERACTION
C       =3: ULTIMATE STRAIN
C       =4: ALL FAILURE OPTIONS
C   ULT(I,J,K) : LIMIT VALUE FOR LAYER K IN DIRECTION I (AXIAL, TRANSVERSE,
C               OR SHEAR) UNDER J (TENSION OR COMPRESSION)
C   STIFF : RATIO (TANGENT MODULUS TO INITIAL MODULUS) AT
C           WHICH COMPUTATIONS TERMINATE
C   A12(I) : QUADRATIC INTERACTION TERM (LAYER I)
C   CONTROL SENTINELS
C   KSGM : INCREMENTATION LIMIT
C   SMLT : MULTIPLICATIVE FACTOR FOR LOAD INCREMENTS
C   IT : ITERATION LIMIT PER NEWTON-RAPHSON ANALYSIS
C   FPS : CONVERGENCE CRITERIA
C   UPRI : DIVERGENCE CRITERIA
C   INMT : INCREMENTATION ESTIMATE METHOD
C
C * VARIABLE DICTIONARY *
C
C   A0(I) : CURVE-FIT PARAMETER
C   RB0(X,Y,W) : CONVERSION FUNCTION FROM CURVE-FIT PARAMETERS
C               TO RAMBERG-OSGOOD PARAMETERS
C   TT : TOTAL THICKNESS
C   SG(I,1) : RESULTANT AXIAL STRESS FOR ITH LAYER
C   SG(I,LAY,1) : RESULTANT TRANSVERSE STRESS FOR ITH LAYER
C   SG(I,2*LAY,1) : RESULTANT SHEAR ITH LAYER
C   SGS(I) : AXIAL STRESS (ITH LAYER) FROM PREVIOUS INCREMENT
C   SGS(I+LAY) : TRANSVERSE STRESS (ITH LAYER) FROM PREVIOUS LOAD
C   SGS(I+2*LAY) : SHEAR (ITH LAYER) FROM PREVIOUS LOAD
C   SG0(I,1) : INITIAL LOAD
C   S11(I) : COMPLIANCE TERM
C   S12(I) : COMPLIANCE TERM
C   S21(I) : COMPLIANCE TERM
C   S22(I) : COMPLIANCE TERM
C   S44(I) : COMPLIANCE TERM
C   SINS(I) : SQUARE OF SIN OF ITH LAYER
C   COSX(I) : SQUARE OF COS OF ITH LAYER
C   SIN2(I) : TWICE SIN OF ITH LAYER
C   COS2(I) : TWICE COS OF ITH LAYER
C   A(I,J) : INITIAL TRANSFORMATION MATRIX
C   NB(I,J) : MATRIX OF DERIVATIVE TERMS FOR N-R, APPROX.
C   DC(I) : MULTIPLIER OF DERIVATIVE MATRIX (DB)
C   RT(I) : INCREMENTAL CHANGE IN STRESS SOLUTION BETWEEN
C           N-R ITERATES
C   SG1(I,1) : STRESS SOLUTION FROM PREVIOUS NEWTON-RAPHSON
C               ITERATION FOR A GIVEN LOAD
C   P11(I) : AXIAL STRAIN LAYER AXES (ITH LAYER)
C   P22(I) : TRANSVERSE STRAIN LAYER AXES (ITH LAYER)

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```

C P12(I)
C EP11(I)
C EP22(I)
C EP12(I)
C SF(I)
C
C PS(I)
C PS(I+LAYER)
C PS(I+2*LAYER)
C FPS11(I)
C FPS22(I)
C FPS12(I)
C
C SWITCH
C
C NIT
C
C NSR
C
C *****
C INITIALIZE VARIABLES
C
C EX=3.
C INMT=2
C RATIO=1.E-06
C SENS=1.E-15
C
C PRINT PROGRAM HEADER
C CALL HEADER
C NST=1
C 423 CONTINUE
C
C IPRINT=0
C CALL MATCRL (NSR)
C IF (NSR.EQ.1) GO TO 424
C CHANGE ENGINEERING STRAIN TO TENSORIAL STRAIN.
C 425 DO 63 ILKA=1,50
C DO 63 ILKB=1,20
C 63 POINTS(ILKA,6,ILKB) = POINTS(ILKA,6,ILKB)/2.
C
C *****
C INPUT PER SET
C *****
C
C GO TO (20,30),IOPT
C INPUT 11
C 20 CONTINUE
C GO TO 50
C INPUT 21
C 30 CONTINUE
C IF (COPT.EQ.1) LUP=1
C IF (COPT.EQ.2) LUP=LAY
C DO 40 IL=1,LUP
C INPUT STRESS-STRAIN DATA AND FIT CURVE OF FORM:

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```

C
C
000067      STRN = A0 + A1*STRS**EX
000070      WHERE A0 = A*STRS
000071      NO 40 IC=1.3
000072      NO 45 INT=1.1PTS
000073      STRN(IDT)=POINTS(IDT,2*IC-1,LUP)
000074      STPS(IDT)=POINTS(IDT,2*IC-1,LUP)
000075      IF(IC.EQ.1) A0(IDT) = STRS(IDT)/G12(IL)
000076      IF(IC.EQ.2) A0(IDT) = STRS(IDT)/E22(IL)
000077      IF(IC.EQ.3) A0(IDT) = STRS(IDT)/E22(IL)
000078      STRN(IDT) = STRN(IDT) - A0(IDT)
000079      IF(STRN(IDT).LE.1.0E-20) STRN(IDT) = 0.00
000080      35 CONTINUE
C
C      LEAST-SQUARES CURVE-FIT FOR STRESS-STRAIN DATA
000081      CALL REGA1(STRS,STRN,IPTS,EOPT,0.,A1,EX,0)
000082      IF(IC.EQ.1) TY(IL) = RR0(G12(IL),A1,EX)
000083      IF(IC.EQ.2) XM = EX
000084      IF(IC.EQ.3) STY(IL) = RR0(F22(IL),A1,EX)
000085      IF(IC.EQ.2) XN = EX
000086      IF(IC.EQ.3) SCY(IL) = RR0(E22(IL),A1,EX)
000087      IF(IC.EQ.3) XN = EX
000088      40 CONTINUE
000089      IF(COPT.NE.1) GO TO 50
000090      NO 43 IL=2,LAY
000091      TY(IL) = TY(1)
000092      STY(IL) = STY(1)
000093      SCY(IL) = SCY(1)
000094      43 CONTINUE
000095      50 CONTINUE
C
C      INPUT LOADINGS AND FAILURE CRITERIA
000096      INPUT ANALYSIS CONTROL PARAMETERS
000097      PRINT INPUT
000098      CALL OUTPT1(NST,LAY,IFCN,KSGM)
000099
000100      *****
000101      * INITIAL ASSIGNMENTS *
000102      * AND *
000103      * COMPUTATIONS *
000104      *****
C
C      ANGLE REDUCTION ROUTINE
000105      CALL ANGLE(LAY,IANG)
000106
000107      SWITCH = 0
000108      TT = 0.0E0
000109      NO 100 T = 1,LAY
000110      TT = TT + T(1)
000111      100 CONTINUE
C
000112      UFAIL(1) = 0
000113      UFAIL(2) = 0
000114      UFAIL(3) = 0
000115      AGAIN = 0
000116      KSG = 1
000117      LT1 = LAY
000118      N = 1
000119      LP1 = LAY + 1

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HJN VERSION 2.3 --PSR LEVEL 363--

```

000247      LT2 = LAY*2
000250      LT21 = LAY*2+1
000251      LT3 = LAY*3
000252      LM1 = LAY -1
C
000253      DO 105 I=1,LT3
000255      SG(I,1) = 0.000E 00
000256      SGS(I) = 0.0E00
000257      SF(I) = 1.0E0
000261      SGO(I,1) = 0.0E0
000262      105 CONTINUE
C
000264      DO 107 I = 1,LAY
000265      S11(I) = 1.0E0/E11(I)
000267      S12(I) = -V12(I)/E11(I)
000272      S21(I) = -V21(I)/E22(I)
000274      107 CONTINUE
C
C      PRINT INITIAL ELASTIC LAMINATE CONSTANTS
C      CALL PROP(SG*EXX,EYY,VXY,GXY,KSGM,KSG,LAY,1)
C
C      *****
C      *      INCREMENTAL      *
C      *      ANALYSIS      *
C      *****
C
C      RETURN TO 110 FOR NEXT INCREMENTAL STEP
C
000310      110 CONTINUE
000310      MSING = .FALSE.
000311      MSINGD = .FALSE.
000312      NIT = 0
000313      IPT = 0
000314      SGO1 = S011
000315      SGO2 = S022
000317      SGO3 = S012
C
000320      DO 111 K = 1,LT3
000322      DC(K) = 0.0E0
000323      SG1(K,1) = 0.0F0
000324      DO 111 L=1,LT3
000326      DB(K,L) = 0.0E0
000331      A(K,L) = 0.0E0
000334      111 CONTINUE
000341      DO 1115 I=1,N
000342      S22(I) = 1.0F0/E22(I)
000344      S44(I) = 1.0F0/(4.0E0*G12(I))
000347      1115 CONTINUE
C
C      AFTER 2ND INCREMENTATION USE MULTIPLICATIVE FACTOR
C      AS INITIAL STRESS SOLUTION ESTIMATE
C      IF (KSG.GE.3 .AND. IPT.EQ.0) GO TO 120
000351      112 CONTINUE
000360      JF(N.EQ.1) LM1=1
000363      DO 115 I=1,LM1

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000365      SNS = SINS(I)
000367      CSS = COSX(I)
000370      SN2 = SIN2(I)
000372      CS2 = COS2(I)
C
000373      IF(N.EQ.1) GO TO 113
000375      SNSP = SINS(I+1)
000377      CSSP = COSX(I+1)
000400      SN2P = SIN2(I+1)
000402      CS2P = COS2(I+1)
C
000403      113 CONTINUE
000403      A(1,I) = CSSP*(I)
000407      A(1,I+N) = SNSP*(I)
000414      A(1,I+2*N) = -SN2P*(I)
C
000422      A(2,I) = SNSP*(I)
000426      A(2,I+N) = CSSP*(I)
000432      A(2,I+2*N) = SN2P*(I)
C
000440      A(3,I) = SN2P*(I)/2.0E0
000444      A(3,I+N) = -SN2P*(I)/2.0E0
000451      A(3,I+2*N) = CS2P*(I)
000455      IF(N.EQ.1) GO TO 116
C
000457      A(3,I+1,I) = -S11(I)*CSS-S21(I)*SNS
000465      A(3,I+1,I+1) = S11(I+1)*CSSP+S21(I+1)*SNSP
000474      A(3,I+1,I+N) = -S12(I)*CSS-S22(I)*SNS
000503      A(3,I+1,I+N+1) = S12(I+1)*CSSP+S22(I+1)*SNSP
000512      A(3,I+1,I+2*N) = 2.0E0*S44(I)*SN2
000521      A(3,I+1,I+2*N+1) = -2.0E0*S44(I+1)*SN2P
C
000530      A(3,I+2,I) = -S11(I)*SNS-S21(I)*CSS
000536      A(3,I+2,I+1) = S11(I+1)*SNSP+S21(I+1)*CSSP
000545      A(3,I+2,I+N) = -S12(I)*SNS-S22(I)*CSS
000554      A(3,I+2,I+N+1) = S12(I+1)*SNSP+S22(I+1)*CSSP
000563      A(3,I+2,I+2*N) = -2.0E0*S44(I)*SN2
000572      A(3,I+2,I+2*N+1) = 2.0E0*S44(I+1)*SN2P
C
000601      A(3,I+3,I) = -(S11(I)-S21(I))*SN2/2.0E0
000610      A(3,I+3,I+1) = (S11(I+1)-S21(I+1))*SN2P/2.0E0
000620      A(3,I+3,I+N) = -(S12(I)-S22(I))*SN2/2.0E0
000627      A(3,I+3,I+N+1) = (S12(I+1)-S22(I+1))*SN2P/2.0E0
000636      A(3,I+3,I+2*N) = -2.0E0*S44(I)*CS2
000644      A(3,I+3,I+2*N+1) = 2.0E0*S44(I+1)*CS2P
C
000653      115 CONTINUE
C
000655      A(1,N) = CSSP*(N)
000661      A(1,2*N) = SNSP*(N)
000665      A(1,3*N) = -SN2P*(N)
000672      A(2,N) = SNSP*(N)
000676      A(2,2*N) = CSSP*(N)
000702      A(2,3*N) = SN2P*(N)
000706      A(3,N) = SN2P*(N)/2.0E0

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000712      A(3,2*N) = -SN2P*T(N)/2.0E0
000716      A(3,3*N) = CS2P*T(N)
000723      116 CONTINUE
000723      IF(MSING) GO TO 117
C
C
C      INVERT MATRIX A
000725      CALL INVERT(A,60,LT3,DET, SFMS ,IRANK,1.00E-30)
C
C      CHECK FOR SINGULAR MATRIX
000733      IF(IRANK.EQ.LT3) GO TO 118
000735      MSING = .TRUE.
000736      WRITE(6,1420) IRANK,DET
000745      GO TO 112
000746      117 CONTINUE
000746      WRITE(6,1425) ((A(K1,L1),L1=1,LT3),K1=1,LT3)
000746      MSING = .FALSE.
000766      GO TO 990
000767      118 CONTINUE
000770
C
C      INITIAL LOAD VECTOR
000770      IF (SWITCH.EQ.1) GO TO 119
000772      SGO(1,1) = S011*IT
000774      SGO(2,1) = S022*IT
000776      SGO(3,1) = S012*IT
000777      119 CONTINUE
000777      CALL MMXUL0(A,SGO,SG,60,60,1,LT3,LT3,1)
C
C      RESET STRESS = 0, IF RELATIVE STRESS ) 1.0D-06
001010      CALL RESET(LT3,SG, RATIO )
001013      GO TO 126
C
C      (MULTIPLICATIVE FACTOR) X (SOLUTION FROM PREVIOUS INCREMENT)
001014      120 CONTINUE
001014      DO 122 I=1,LT3
001016      SG(I,1) = SF(I)*SGS(I)
001021      122 CONTINUE
001023      GO TO 126
C
C      RETURN TO 125 FOR NEXT ITERATION STEP
001023      125 CONTINUE
001023      NIT = NIT + 1
001025      126 CONTINUE
C      STORE STRESS SOLUTION FOR THIS ITERATION
001025      DO 127 I=1,LT3
001027      SG1(I,1) = SG(I,1)
001031      RT(I) = 0.0E 00
001032      127 CONTINUE
C
C      130 CONTINUE
001034      DO 1305 K=1,LT3
001034      DO 1305 L=1,LT3
001036      DB(K,L) = 0.0E 00
001037

```

MAIN

```

001042      C      1305 CONTINUE
C      *****
C      * DERIVATIVE MATRIX *
C      * FOR *
C      * NEWTON-RAPHSON ANALYSIS *
C      *****
001046      IF(N.EQ.1) LM1=1
001051      DO 151 I=1,LM1
C      CALCULATION OF TERMS USED IN FORMATION OF DERIVATIVE MATRIX
001053      IF(N.EQ.1) GO TO 1308
001055      CALL NRTRM (LAY,SG,F,G,H,I)
001061      CALL NRTRM (LAY,SG,F,G,H,I+1)
001067      1308 CONTINUE
C
001067      SNS = SINS(I)
001071      CSS = COS(I)
001073      SN2 = SIN2(I)
001074      CS2 = COS2(I)
C
001076      IF(N.EQ.1) GO TO 131
001100      SNSP = SINS(I+1)
001101      CSSP = COS(I+1)
001103      SN2P = SIN2(I+1)
001104      CS2P = COS2(I+1)
C
C      131 CONTINUE
001106      DB(1,I) = CSS*(I)
001106      DB(1,I+N) = SNS*(I)
001112      DB(1,I+2*N) = -SN2*(I)
001117      DB(2,I) = SNS*(I)
001125      DB(2,I+N) = CSS*(I)
001131      DB(2,I+2*N) = SN2*(I)
001135      DB(3,I) = SN2*(I)/2.
001143      DB(3,I+N) = -SN2*(I)/2.
001147      DB(3,I+2*N) = CS2*(I)
001154      IF(N.EQ.1) GO TO 161
001160
C
001162      DB(3*I+1,I) = -F(1,I)
001167      DB(3*I+1,I+1) = F(1,I+1)
001174      DB(3*I+1,I+N) = -F(2,I)
001201      DB(3*I+1,I+N+1) = F(2,I+1)
001207      DB(3*I+1,I+2*N) = -F(3,I)
001215      DB(3*I+1,I+2*N+1) = F(3,I+1)
C
001223      DB(3*I+2,I) = -G(1,I)
001231      DB(3*I+2,I+1) = G(1,I+1)
001236      DB(3*I+2,I+N) = -G(2,I)
001243      DB(3*I+2,I+N+1) = G(2,I+1)
001251      DB(3*I+2,I+2*N) = -G(3,I)
001260      DB(3*I+2,I+2*N+1) = G(3,I+1)
C
001266      DB(3*I+3,I) = -H(1,I)
001274      DB(3*I+3,I+1) = H(1,I+1)
001301      DB(3*I+3,I+N) = -H(2,I)
001306      DB(3*I+3,I+N+1) = H(2,I+1)

```


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MAIN

```

001510 DC(2) = DC(2) + SG(I,1)*SNS*T(I) + SG(LAY+I,1)*CSS*T(I)
1      + SG(2*LAY+I,1)*SN2*T(I)
001524 DC(3) = DC(3) + SG(I,1)*T(I)*SN2/2. - SG(LAY+I,1)*T(I)*
1      SN2/2. + SG(2*LAY+I,1)*CS2*T(I)
001540 6 CONTINUE

```

```

C
C FORM NON-LINEAR COMPLIANCE TERMS S22 AND S44
DO 7 K=1,N

```

```

001543 DO 7 K=1,N
001544 T125 = (SG(K+2*N,1)/TY(K))*2
001550 IF(SG(K+N,1)-0.0) 1,2,2
001553 1 TS225 = (SG(K+N,1)/SCY(K))*2
001557 GO TO 3
001557 2 TS225 = (SG(K+N,1)/STY(K))*2
001563 3 S125 = T125 + TS225
001565 S22(K) = (1.0E0+S125**((XN-1.)/2.))/E22(K)
001577 S44(K) = (1.0E0+S125**((XM-1.)/2.))/(4.0E0*G12(K))
001612 7 CONTINUE

```

```

C
IF(N.EQ.1) GO TO 5008
DO 8 K=1,LM1

```

```

001614 SNS = SINS(K)
001616 CSS = COSS(K)
001621 SN2 = SIN2(K)
001624 CS2 = COS2(K)
001625 SNSP = SINS(K+1)
001627 CSSP = COSS(K+1)
001630 SN2P = SIN2(K+1)
001632 CS2P = COS2(K+1)

```

```

001633 DC(3+3*K-2) = -(S11(K)*CSS+S21(K)*SNS)*SG(K,1) -
1      SG(LAY+K,1)*(S12(K)*CSS+S22(K)*SNS) + 2.*S44(K)*SN2
2      SG(2*LAY+K,1) + (S11(K+1)*CSSP+S21(K+1)*SNSP)
3      *SG(K+1,1) + (S12(K+1)*CSSP+S22(K+1)*SNSP)*
4      SG(LAY+K+1,1) - 2.*S44(K+1)*SG(2*LAY+K+1,1)*
5      SN2P + SG(3+3*K-2,1)

```

```

001706 DC(3+3*K-1) = -(S11(K)*SNS+S21(K)*CSS)*SG(K,1) - (S12(K)*SNS+
1      S22(K)*CSS)*SG(LAY+K,1) - 2.*S44(K)*SN2*
2      SG(2*LAY+K,1) +
3      (S11(K+1)*SNSP+S21(K+1)*CSSP)*SG(K+1,1) + (S12(K+1)*
4      SNSP+S22(K+1)*CSSP)*SG(LAY+K+1,1) + 2.*S44(K+1)*SN2P
5      *SG(2*LAY+K+1,1) + SG(3+3*K-1,1)

```

```

001761 DC(3+3*K) = -(S11(K)-S21(K))*SN2*SG(K,1)/2. - (S12(K)-S22(K))*
1      SN2*SG(LAY+K,1)/2. - 2.*S44(K)*CS2*SG(2*LAY+K,1) +
2      (S11(K+1)-S21(K+1))*SN2P*SG(K+1,1)/2. + (S12(K+1)-
3      S22(K+1))*SN2P*SG(LAY+K+1,1)/2. + 2.*S44(K+1)*CS2P*
4      SG(2*LAY+K+1,1) + SG(3+3*K,1)

```

```

002035 8 CONTINUE
002037 5008 CONTINUE

```

```

C
DO 9 I=1,LT3
002037 DC(I) = -DC(I)
002041 9 CONTINUE

```

```

C
DO 11 I=1,LT3
002045 DO 11 K=1,LT3
002046

```

MAIN

RUN VERSION 2.3 --PSR LEVEL 363--

```

002047      11 RT(I) = RT(I) + DB(I,K)*DC(K)
C          *****
C          * FORM SOLUTION VECTOR *
C          * FOR *
C          * THIS ITERATION *
C          *****
C
C      DO 15 I=1,LT3
C          SG(I,1) = SG(I,1) + RT(I)
C      15 CONTINUE
C
C      RESET STRESS = 0, IF RELATIVE STRESS ) 1.0D-06
C      CALL RESET(LT3,SG, RATIO )
C      IF(NIT.EQ.0) GO TO 125
C
C      *****
C      * CONVERGENCE CHECK *
C      *****
C
C      CALL CONVR(LAY,SG,SG1,KSG,IRTN)
C      GO TO (495,125,900),IRTN
C      495 CONTINUE
C      IF(SWITCH.EQ.0) GO TO 500
C      SG01 = SG0(1,1)/IT
C      SG02 = SG0(2,1)/IT
C      SG03 = SG0(3,1)/IT
C      500 CONTINUE
C
C      *****
C      * STRAIN COMPUTATIONS *
C      *****
C
C      DO 540 I = 1,LAY
C          SNS = SINS(I)
C          CSS = COS5(I)
C          SN2 = SIN2(I)
C          CS2 = COS2(I)
C
C          STRAIN COMPUTATIONS IN FIBER AXES DIRECTIONS
C          P11(I) = S11(I)*SG(I,1) + S12(I)*SG(I+N,1)
C          T12S = (SG(I+2*N,1)/TY(I))*2
C          IF(SG(I+N,1)-C.0) 4,5,5
C          4 TS22S = (SG(I+N,1)/SCY(I))*2
C          GO TO 18
C          5 TS22S = (SG(I+N,1)/STY(I))*2
C          18 S12S = T12S + TS22S
C          P22(I) = S21(I)*SG(I,1) + SG(I+N,1)/E22(I)*(1.0E0+S12S**((XN
C          1 P12(I) = SG(I+2*N,1)/(2.*G1P(I))*(1.0E0+S12S**((XN-1.)/2.))
C      520 CONTINUE
C          EPN(I ,1) = P11(I)
C          EPN(I+ N,1) = P22(I)
C          EPN(I+2*N,1) = P12(I)
C
C          STRAIN COMPUTATIONS IN LAMINATE AXES DIRECTIONS
C          EP11(I) = P11(I)*CSS + P22(I)*SNS - P12(I)*SN2
C          EP22(I) = P11(I)*SNS + P22(I)*CSS + P12(I)*SN2

```

002221
002227

```

002235 C      FPI2(I) = (P11(I)-P22(I))*SN2/2.E0 + P12(I)*CS2
002243 C      540 CONTINUE
002244 IF (AGAIN.EQ.1) GO TO 752
002250 IF (SWITCH.EQ.0) GO TO 610
002251 SWITCH = 0
002251 IPT = 1
002252 GO TO 730

C
C
C *****
C * LAMINATE FAILURE TESTS *
C *****
C
002253 C      610 CONTINUE
002253 CALL LAMTST(LAY,SG,SGS,EPN,PS,KSG,KSGM,IFCN,UFAIL,FAC,SWITCH)

C
C *****
C * OUTPUT PER *
C * LOAD INCREMENT *
C *****
C
002266 C      730 CONTINUE
002266 WRITE(6,1525)
002272 WRITE(6,1527) SG01
002300 WRITE(6,1528) SG02
002306 WRITE(6,1529) SG03
002314 WRITE(6,1735) NIT
002322 WRITE(6,1536)
002326 WRITE(6,1537)
002332 WRITE(6,1538)
002336 DO 750 I = 1,LAY
002340 EPI2(I)=EPI2(I)*2.
002342 WRITE(6,1550) I,SG(I,1),SG(I+N,1),SG(I+2*N,1),
1 EPI1(I),EPI2(I),EPI2(I),P11(I),P22(I),P12(I)
002375 FPI2(I)=FPI2(I)/2.
002400 C      750 CONTINUE
002402 IF(IPT.FQ.1) WRITE(6,1990)
002407 IF (IPT.FQ.1) AGAIN=1
002412 IF(IPT.EQ.1) GO TO 110

C
C COMPUTE INELASTIC MATERIAL PROPERTIES AND RETAIN AS FUNCTION OF INCREMENT
C
002413 C      752 CONTINUE
002413 AGAIN = 0
002414 CALL PROP(SG,EXX,EYY,VXY,GXY,KSGM,KSG,LAY,2)
002426 DO 755 I=1,LAY
002430 STXX(I,KSG) = SG(I ,1)
002434 STYY(I,KSG) = SG(I+N,1)
002441 STXY(I,KSG) = SG(I+2*N,1)
002446 C      755 CONTINUE

C
C CHECK FOR LAMINATE FAILURE, IF FAILURE HAS OCCURED INTERPOLATE LOADS TO
C FAILURE POINT AND REEVALUATE
C IF (SWITCH.FQ.0) GO TO 758
002450 WRITE(6,1555)
002455 WRITE(6,1560)
002461 SG0(1,1) = ((S011-SM11) + FAC*SM11)*TI
002466 SG0(2,1) = ((S022-SM22) + FAC*SM22)*TI

```

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```

002472      SG0(3,1) = ((S012-SM12) + FAC*SM12)*TI
002477      GO TO 110
002477 750 CONTINUE
C
C CHECK FOR INCREMENTATION LIMIT
C IF (KSGM-KSG) 790,790,760
C
C *****
C * INCREMENTATION *
C * ESTIMATE *
C *****
C
002502 760 CONTINUE
002502 GO TO (762,766), INMT
C
C RATIO OF PREVIOUS SOLUTIONS
C 762 CONTINUE
002510 DO 765 I=1,LT3
002510 IF (KSG.EQ.1) GO TO 770
002512 IF (SGS(I).EQ.0.0E0) GO TO 763
002514 SF(I) = SG(I,1)/SGS(I)
002515 GO TO 745
002517 763 CONTINUE
002520 SF(I) = 1.0E0
002520 765 CONTINUE
002522 GO TO 770
002525
C 766 CONTINUE
002525 DO 768 I=1,LT3
002525 IF (KSG.LT.2) GO TO 767
002527 IF (SG(I,1).EQ.0.0E0) GO TO 767
002531 VKSG = KSG + 1
002533 CONS = VKSG*(VKSG-2)/(VKSG-1)**2
002535 SF(I) = 1.0E0 + CONS*(SG(I,1)-SGS(I))/SG(I,1)
002543 GO TO 768
002551 767 CONTINUE
002551 SF(I) = 1.0E0
002551 768 CONTINUE
C
C STORE STRESS AND STRAIN VALUES
C 770 CONTINUE
002556 DO 775 I = 1,LAY
002556 SGS(I) = SG(I)
002560 SGS(I+N) = SG(I+N,1)
002562 SGS(I+2*N) = SG(I+2*N,1)
002566 EPS1(I) = EP1(I)
002572 EPS2(I) = EP2(I)
002573 EPS12(I) = EP12(I)
002575 PS(I) = P1(I)
002576 PS(I+N) = P2(I)
002600 PS(I+2*N) = P12(I)
002602 775 CONTINUE
C
C INCREMENT APPLIED LOADING
C KSG = KSG + 1
002610

```


SUBROUTINE HEADER

```

C
C ROUTINE HEADER PRINTS HEADER INFORMATION FOR NOLIN V2 M2
C
000002 REAL          MESSAGE(100)
C RETRIEVE JULIAN DATE FROM THE OPERATING SYSTEM.....
C DATE=0
C READ IN 5 CARD PROGRAM IDENTIFICATION
C READ(5,200) (MESSAGE(I),I=1,100)
C      200 FORMAT(20A4)
C WRITE OUT TITLE, DATE, AND PROGRAM IDENTIFICATION
C      1000 FORMAT (1H1,///,41X,41(***).3(/,41X,***,39X,***),/,
C      *      41X,***,14X,***NONLINEAR,16X,***,/,41X,***,39X,***,/,
C      *      41X,***,8X,***THERMOELASTIC ANALYSIS, 9X,***,/,
C      *      41X,***,39X,***,/,41X,***,18X,***OF,19X,***,/,
C      *      41X,***,39X,***,/,41X,***,10X,***FIBROUS COMPOSITES,
C      *      11X,***,/,41X,***,39X,***,/,41X,***,17X,***AND,19X,***,/,
C      *      41X,***,39X,***,/,41X,***,6X,
C      *      *NON-HOMOGENEOUS LAMINATES, 8X,***,3(/,41X,***,39X,***),
C      *      /,41X,41(***),//,
C      *      //21X,***VERSION 2      MOD 3 (MAY 74),
C      *      //,21X,***DATE      *,A10,///,21X,
C      *      *.PROGRAM IDENTIFICATION*,,5(21X,20A4,/) ,///)
C
000031 RETURN
000032 END
00003600

```

```

000003 SURROUTINE MATCRL (NSR)
000003 REAL THETA
000003 DIMENSION
1 THETA(20),THICK(20),MATYPE(20),S11T(20),S22T(20),
2 S12(20),S11C(20),S22C(20),EP11T(20),EP22T(20),EP11C(20),
3 EP22C(20),GAMA(20),E11(20),E22(20),G12(20),V12(20),
4 T(20),A12(20),V21(20),TE11(20),TE22(20),TG12(20),
5 TV12(20),TA12(20),TSTY(20),TSCY(20),TY(20),
6 STY(20),SCY(20),EP11(20),EP22(20),EP12(20),AULT(6,2,20),
7 POINTS(50,6,20),EPS11(50,20),EPS22(50,20),EPS12(50,20),
8 TEPS11(50,20),TEPS22(50,20),TEPS12(50,20),
9 SIG11(50,20),SIG22(50,20),SIG12(50,20),A11(20),A22(20),
10 A44(20),B1(20),B2(20),S11(20),S22(20),S21(20),
11 /SET01/ E11,E22,V12,V21,G12
12 /SET02/TT,THICK,THETA
13 /SET03/EP11,EP22,EP12
14 /SET04/ S011,S022,S012,S011,SM11,SM22,SM12
15 /SET05/ ULT,STIFF
16 /SET08/ S11,S22,S12,S21
17 /SET09/ NLAY,EOPT,COPI,IFCN,KSGM,INMT,RATIO,SENS
18 /SET10/ STY,SCY,TY,XN,XN
19 /SET11/ EPS,UPHD,NIT,IT,SMLT
20 /SET14/ A11,A22,A44,A12,B1,B2
21 /SET15/ POINTS,IPRINT,IOP,IPIS,LUP
22 /SET16/ MATYPE,S11T,S11C,S22T,S22C,EP11T,EP11C,
23 EP22T,EP22C,GAMA,SIG11,SIG22,SIG12
24 /SET17/ TE11,TE22,TG12,TV12,TA12,TSTY,TSCY,TTY
25 INTEGER EOPT,COPT
26 NAMELIST/DATA/NLAY,E11,E22,V12,G12,THICK,THETA,IOP,
27 STY,SCY,TY,XN,EUP,COPT,IPIS,IPRINT,S011,S022,S012,
28 IFCN,STIFF,A12,KSGM,SMLI,IT,EPS,UPHD,INMT,RATIO,SENS,
29 S11T,S22T,S12,S11C,S22C,EP11T,EP22T,EP11C,EP22C,
30 GAMA,SIG11,SIG22,SIG12,EPS11,EPS22,EPS12,MATYPE
31 NSR=0
32 READ(5,DATA)
33 IF (EOF,5) 424,425
34 DO 10 I=1,20
35   TE11(I) = E11(I)
36   TE22(I) = E22(I)
37   TG12(I) = G12(I)
38   TV12(I) = V12(I)
39   TA12(I) = A12(I)
40   TSTY(I) = STY(I)
41   TSCY(I) = SCY(I)
42   TTY(I) = TY(I)
43   NO P00 I = 1,20
44   M = MATYPE(I)
45   E11(I) = TE11(M)
46   E22(I) = TE22(M)
47   G12(I) = TG12(M)
48   V12(I) = TV12(M)
49   A12(I) = TA12(M)
50   STY(I) = TSTY(M)
51   SCY(I) = TSCY(M)

```

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MATCRL

RUN VERSION 2.3 --PSR LEVEL 363--

```

100052 TY(I) = ITY(M)
100053 ULT(1,1,I) = S11T(M)
100056 ULT(1,2,I) = S11C(M)
100061 ULT(2,1,I) = S22T(M)
100064 ULT(2,2,I) = S22C(M)
100067 ULT(3,1,I) = S12(M)
100072 ULT(3,2,I) = S12(M)
100075 ULT(4,1,I) = EP11T(M)
100100 ULT(4,2,I) = EP11C(M)
100103 ULT(5,1,I) = EP22T(M)
100106 ULT(5,2,I) = EP22C(M)
100111 ULT(6,1,I) = GAMA(M)
100114 ULT(6,2,I) = GAMA(M)
100117 DO 200 J = 1,IPTS
100121 POINTS(J,1,I) = SIG11(J,M)
100127 POINTS(J,2,I) = EPS11(J,M)
100135 POINTS(J,3,I) = SIG22(J,M)
100143 POINTS(J,4,I) = EPS22(J,M)
100151 POINTS(J,5,I) = SIG12(J,M)
100157 POINTS(J,6,I) = EPS12(J,M)
100171 RETURN
100172 200 NSR=1
100173 424 RETURN
100174 END

```


UN VERSION 2.3 --PSR LFVEL 363--

```

00247 WRITE(6,1526) S022,SM22
00257 WRITE(6,1528) S012,SM12
00267 IFN = 2*IFCN
00273 IST = IFN-1
00275 WRITE(6,1530) (HDFAIL(IF),IF=IST,IFN)
00307 IF(IFCN.NE.2) WRITE(6,1532)
00322 IF((IFCN.NE.2).OR.(IFCN.EQ.4)) IFS=1
00332 IF((IFCN.EQ.2).OR.(IFCN.EQ.4)) WRITE(6,1533)
00350 IF(IFCN.EQ.2) IFS=4
00353 DO 90 IL=1,LAY
00355 85 CONTINUE
00357 IFE = IFS+2
00359 WRITE(6,1534) IL,((ULT(ID,IM,IL),ID=IFS,IFE),IM=1,2)
00404 IF(IFCN.NE.4) GO TO 90
00411 IF(IFS.EQ.1) IFS=4
00414 IF(IFE.EQ.3) GO TO 85
00416 IFS = 1
00417 90 CONTINUE
00422 IF((IFCN.EQ.1).OR.(IFCN.EQ.2)) GO TO 110
00431 WRITE(6,1535)
00435 DO 95 IL=1,LAY
00441 WRITE(6,1536) IL,A12(IL)
00450 95 CONTINUE
00455 110 CONTINUE
00457 WRITE(6,1538) STIFF
00463 WRITE(6,1540)
00467 WRITE(6,1544) IT
00475 WRITE(6,1546) EPS
00503 WRITE(6,1548) UPBD

C
00511 1507 FORMAT(/// ** DATA INPUT POINTS FOR CURVE FIT-*/ **/)
00511 1509 FORMAT (1H1,50X,*LAMINATE*,14,50X,12(* **))
00511 1510 FORMAT (/// ** NUMBER OF LAYERS = *,12)
00511 1513 FORMAT (/ ** LAYER THETA*,6X,*,13X,*E11*, 9X,*E22*, 9X,*
* v12*, 9X,*v21*, 9X,*G12*,8X,*SGT Y*,8X,*SGC Y*,8X,*TAUY*/ **/)
00511 1515 FORMAT (14,3X,F6.2,2X,E11.4,4X,E11.4)
00511 1516 FORMAT (/// ** EQUATION PARAMETERS*)
00511 1517 FORMAT ( * EXPONENT M = *,E12.5)
00511 1520 FORMAT (///50X,*EXTERNALLY APPLIED STRESS*/50X,27(* **),
* /30X,*INITIAL*,18X,*STRESS*, 42X,*NO. OF*
* /32X,*STRESS*,17X,*INCHMENT*,37X,*INCREMENTS*/ **/)
00511 1524 FORMAT (15X,*SG XX*,4X,E15.5,11X,E15.5, 37X,15)
00511 1526 FORMAT (15X,*SG YY*,4X,E15.5,11X,E15.5)
00511 1528 FORMAT (15X,*SG XY*,4X,E15.5,11X,E15.5)
00511 1530 FORMAT (///50X,*LAMINA FAILURE CRITERIA*,/50X,23(* **),
* /52X,2A10,///16X,*LAYER*,18X,*LL*,23X,*TT*,25X, *LT*/ **/)
00511 1532 FORMAT ( 25X,*ULT. STRESS*)
00511 1533 FORMAT (25X,*ULT. STRAIN*/25X,*NOTE: ALL STRAINS ARE ENGINEER*,
* ING COMPONENTS*)
00511 1534 FORMAT (/16X,12, 4X,*TENS.**, 4X,3(E15.5,10X),/22X,*COMP.**,
* 4X,3(E15.5,10X))
00511 1535 FORMAT (/15X,*LAYER*,20X,*QUADRATIC INTERACTION TERM (A12)*/ **/)
00511 1536 FORMAT (16X,12,27X,E15.5)

```

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OUTPUT

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```
00511 1538 FORMAT (/15X,*STIFFNESS = *,E15.5)
00511 1540 FORMAT (/15X,*CONTROL PARAMETERS*,/50X,18(*,*,//))
00511 1544 FORMAT (15X,*MAX. NO. OF ITERATIONS = *,I5)
00511 1546 FORMAT (15X,*CONVERGENCE CRITERIA = *,E15.5)
00511 1548 FORMAT (15X,*DIVERGENCE CRITERIA = *,E15.5)
00511 1553 FORMAT(1X,RE14.5/3X,2E14.5//)
```

C

```
00511 RETURN
00512 END
```

```

C
C SUBROUTINE PROP(SG,EXX,EYY,VXY,VYX,GXY,KSGM,ILD,LAY,LPROP)
C ROUTINE PROP COMPUTES INITIAL LAMINATE CONSTANTS (LPROP=1)
C OR NONLINEAR LAMINATE PROPERTIES AS FUNCTION OF RESULTANT STRESS (LPROP=2)
C
C * VARIABLE DICTIONARY *
C
C CSUM(I,J) : THICKNESS WEIGHTED SUM OF LAYER STIFFNESSES
C           IN LAMINATE COORDINATES
C HEL       : LONGITUDINAL YOUNG'S MODULUS OF LAMINATE
C HET       : TRANSVERSE YOUNG'S MODULUS OF LAMINATE
C NULT      : POISSON RATIO IN LONG.-TRANS.
C NUTL      : POISSON RATIO IN TRANS.-LONG.
C HGLT      : IN-PLANE SHEAR MODULUS OF LAMINATE
C
C *****
C DIMENSION TNS(3,3),CMT(3,3),TMP(3,3),CSUM(3,3),
C           EXX(KSGM),EYY(KSGM),VXY(KSGM),VYX(KSGM),GXY(KSGM)
C DIMENSION T(20),SG(60,1),IANG(20)
C DIMENSION H(25),TH(25),A(3,3)
C REAL IANG,NULT,NUTL
C EQUIVALENCE (CSUM(1),A(1))
C COMMON /SET02/ TT,T,IANG
C
C *****
C INITIALIZE
C DO 30 J=1,3
C DO 30 J=1,3
C CSUM(I,J) = 0.00
C 30 CONTINUE
C
C GO TO (50,75), LPROP
C 50 CONTINUE
C T0 = TT/2.
C H0 = -T0
C TSUM = T(1)
C TH(1) = T(1)
C H(1) = H0 + T(1)
C DO 62 K=2,LAY
C TSUM = TSUM + T(K)
C H(K) = H0 + TSUM
C TH(K) = H(K) - H(K-1)
C 62 CONTINUE
C GO TO 90
C
C 75 CONTINUE
C DO 85 K=1,LAY
C TH(K) = T(K)/TT
C 85 CONTINUE
C 90 CONTINUE
C
C GENERATE SIMILARITY MATRIX OF CMT FOR EACH LAYER
C CSIM = TNS*(-1) * CMT * TNS
C DO 150 K=1,LAY

```

PROP

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```

0070 CALL TRANS(TNS,K)
0072 CALL CMATX(CMT,SG,LAY,K,LPROP)
0103 CALL MXMULD(CMT,TNS,TMP,3,3,3,3,3,3)
0114 CALL INVRD(TNS,3,3,DET,1.0E-12,IRANK,1.0E-30)
0123 CALL MXMULD(TNS,TMP,CMT,3,3,3,3,3,3)
0134 DO 110 KI=1,3
0141 DO 110 KJ=1,3
0142 CSUM(KI,KJ)=CSUM(KI,KJ)+CMT(KI,KJ)*TH(K)
0152 110 CONTINUE
0156 150 CONTINUE
C
C INVERT RESULTANT MATRIX
C CALL INVRD(CSUM,3,3,DET,1.0E-12,IRANK,1.0E-30)
C
0161 60 TO (175,500), LPROP
0167 175 CONTINUE
0201 HEL = 1./A(1,1)*TT
0204 HET = 1./A(2,2)*TT
0207 NULT = -A(1,2)/A(1,1)
0211 NUTL = -A(1,2)/A(2,2)
0213 HGLT = 1./A(3,3)*TT
0216 WRITE(6,1510)
0222 WRITE(6,1522) HEL
0230 WRITE(6,1524) HET
0236 WRITE(6,1526) NULT
0244 WRITE(6,1528) NUTL
0252 WRITE(6,1532) HGLT
0260 WRITE(6,1560)
0264 RETURN
C
C 500 CONTINUE
C COMPUTE NONLINEAR PROPERTIES AS FUNCTION OF STRESS
C FXX(ILD) = 1./CSUM(1,1)
0265 EYY(ILD) = 1./CSUM(2,2)
0274 VXY(ILD) = -CSUM(1,2)/CSUM(1,1)
0276 VYX(ILD) = -CSUM(1,2)/CSUM(2,2)
0300 GXY(ILD) = 1./CSUM(3,3)
0303 RETURN
C
1510 FORMAT (//45X,*LAMINATE CONSTANTS (STRESS-STRAIN)*,/45X,36(**,*) )
0305 1522 FORMAT ( /48X,*EXX = *,E15.5)
0305 1524 FORMAT ( /48X,*EYY = *,E15.5)
0305 1526 FORMAT ( /48X,*VXY = *,E15.5)
0305 1528 FORMAT ( /48X,*VYX = *,E15.5)
0305 1532 FORMAT ( /48X,*GXY = *,E15.5)
0305 1560 FORMAT (1H,50X,*APPLIED STRESS ANALYSIS*/50X,22(**,*) )
0305 END

```



```

SUBROUTINE CMATX(C,SG,N,I,LP,PROP)
C
C ROUTINE CMATX COMPUTES C MATRIX
C
COMMON /SET01/ E11,E22,V12,V21,G12
COMMON /SET10/ STY,SCY,TY,XM,XN
DIMENSION E11(20),E22(20),V12(20),V21(20),G12(20),
1 SCY(20),STY(20),TY(20)
DIMENSION SG(60,1),C(3,3)
DENOM = 1.0-V12(I)*V21(I)
C(1,1) = E11(I)/DENOM
C(2,2) = E22(I)/DENOM
IF(LP,PROP, EQ.1) C(3,3) = 2.*G12(I)
IF(LP,PROP, EQ.2) C(3,3) = G12(I)/(1.0+(SG(I+2*N,1)/TY(I))*2)
C(1,2) = V12(I)*E22(I)/DENOM
C(2,1) = C(1,2)
C(1,3) = 0.0
C(2,3) = 0.0
C(3,1) = 0.0
C(3,2) = 0.0
C
10045 RETURN
10046 END

```

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```

C
C SUBROUTINE REGAL(X,Y,IPIS,OPT,A0,A1,M,IPRT)
C ROUTINE REGAL PERFORMS LEAST-SQUARES CURVE-FIT TO
C GEOMETRIC CURVE OF FORM:  $Y = A0 + A1 \cdot X^M$ 
C
C * VARIABLE DICTIONARY *
C
C OPT = 1: DETERMINE A1 + M.      IPRT = 0: DO NOT PRINT RESULTS
C   = 2: DETERMINE M             = 1: PRINT RESULTS
C   = 3: DETERMINE A1
C
C A0: INTERCEPT (PASSED TO SUBROUTINE)
C A1: COEFFICIENT (PASSED TO/OR DETERMINED BY SUBROUTINE)
C M: EXPONENT (PASSED TO/OR DETERMINED BY SUBROUTINE)
C
C *****
C INTEGER      OPT
C REAL         M
C DIMENSION    X(IPIS),Y(IPIS),OPTION(3)
C EQUIVALENCE  (SX,SNUM),(SY,SDEN)
C DATA        OPTION/10H A1 AND M,10H M ONLY,
C              10H A1 ONLY/
C *
C N=IPIS
C
C INITIALIZE PARTIAL SUMS TO ZERO
C SX = 0.0
C SX2 = 0.0
C SY = 0.0
C SY2 = 0.0
C SXY = 0.0
C NDELET = 0
C
C CHOSE APPROPRIATE CURVE-FIT OPTION
C GO TO (50,250,500),OPT
C
C FIT M AND A1
C 50 CONTINUE
C DO 100 I = 1,N
C   DELETE DATA POINTS YIELDING NEGATIVE ARGUMENTS
C   CONVERT TO LOG FORM
C   IF((Y(I)-A0).LE.1.E-20) GO TO 80
C   XP = ALOG(X(I))
C   YP = ALOG(Y(I)-A0)
C   COMPUTE INTERMEDIATE SUMS, SUM SQUARES, AND CROSS PRODUCT SUMS
C   SX = SX + XP
C   SX2 = SX2 + XP**2
C   SY = SY + YP
C   SY2 = SY2 + YP**2
C   SXY = SXY + XP*YP
C   GO TO 100
C 80 CONTINUE

```

```

10072 NDELET = NDELET + 1
10074 100 CONTINUE
10077 C
10100 N = N - NDELET
10100 COMPUTE REGRESSION EQUATION PARAMETERS
10111 M = (SXY - SX*SY/N)/(SX2 - SX**2/N)
10111 A1 = EXP(SY/N - M*SX/N)
10123 COMPUTE CORRELATION COEFFICIENT (ABS. VAL.)
10143 R = (N*SXY-SX*SY)/SQRT((N*SX2-SX**2)*(N*SY2-SY**2))
10144 R = ABS(R)
10144 GO TO 800
C
10150 FIT M ONLY
10150 250 CONTINUE
10150 GO TO 800
C
10151 FIT A1 ONLY
10151 500 CONTINUE
10151 DO 550 I=1,N
10153 YP = Y(I)-A0
10156 XP = X(I)
10160 SNUM = SNUM + YP*XP**M
10166 SDEN = SDEN + XP** (2.*M)
10175 550 CONTINUE
10177 A1 = SNUM/SDEN
10201 R = 1.
C
C
C PRINT OPTIONS
10202 800 CONTINUE
10202 IF (IPRT.F0.0) RETURN
10204 WRITE(6,1500)
10210 WRITE(6,1510) OPTION(OPT)
10225 WRITE(6,1515) R
10233 WRITE(6,1520) A0
10245 WRITE(6,1524) A1
10257 WRITE(6,1528) M
C
10265 IF (NDELET.NE.0) WRITE(6,1810) NDELET
C
C
1500 FORMAT (1H1,////49X,*LEAST SQUARES REGRESSION ANALYSIS OF FORM*/
* 60X,*Y = A0 + A1*X.*M*////)
1510 FORMAT (50X,*FIT PARAMETERS *A10)
1515 FORMAT (50X,*CORRELATION COEFFICIENT OF LOG CURVE = *,F6.2//)
1520 FORMAT (50X,*A0 = *,1PE15.5)
1524 FORMAT (50X,*A1 = *,1PE15.5)
1528 FORMAT (50X,* M = *,1PE15.5)
1810 FORMAT (1H1,10X,*CURVE-FIT WARNING*/25X,15,
* * DATA POINTS YIELD NEGATIVE LOG ARGUMENTS AND*,
* * HAVE BEEN DELETED*)
C
10303 * RETURN
10303 *
10304 END

```

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```

C
C
C
C
SURROUTINE ANGLE(LAY, IANG)
ROUTINE ANGLE REDUCES ANGLES TO VALUES BETWEEN 0 AND PI/4 FOR
COMPUTING SIN AND COS
C
REAL IANG, IAVL, IANG2
DIMENSION SINS(20), COSS(20), SIN2(20), COS2(20), IANG(20)
COMMON /SET06/ SIN2, COS2, SINS, COSS
DO 72 I = 1, LAY
  IANG2 = 2*IANG(I)
  ANG = IANG(I)
  ANG2 = IANG2
  RAD = ANG / 57.295779513D0
  RAD2 = ANG2 / 57.295779513D0
  IAVL = ABS(IANG(I))
  IF (IAVL.EQ.0.0) GO TO 66
  IF (IAVL.NE.90.0) GO TO 62
  SINS(I) = COS(0.0E0)**2
  COSS(I) = SIN(0.0E0)**2
  SIN2(I) = SIN(0.0E0)
  COS2(I) = -COS(0.0E0)
  GO TO 72
62 CONTINUE
  SGN = IANG(I)/IAVL
  IF (IAVL.NE.45.0) GO TO 64
  SIN2(I) = COS(0.0E0)*SGN
  COS2(I) = SIN(0.0E0)
  GO TO 68
64 CONTINUE
  IF (IAVL.LT.45.0) GO TO 66
  RDA = (2.*IAVL-90.)/57.295779513
  SIN2(I) = SGN* COS(SGN*RDA)
  COS2(I) = -SGN* SIN(SGN*RDA)
  GO TO 68
66 CONTINUE
  SIN2(I) = SIN(RAD2)
  COS2(I) = COS(RAD2)
68 CONTINUE
  SINS(I) = SIN(RAD)**2
  COSS(I) = COS(RAD)**2
72 CONTINUE
RETURN
END
10005
10005
10005
10005
10006
10011
10012
10014
10027
10041
10043
10045
10047
10052
10056
10062
10066
10070
10070
10072
10075
10101
10104
10106
10106
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10136
10142
10142
10146
10152
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10156

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```

00014 SUBROUTINE MXMULD(A,B,C,NROWA,NCOLA,NCOLB,MA,NA,NB) R06D0001
C
C ROUTINE MXMULD MULTIPLIES TWO MATRICES (A + B), STORES RESULT IN C
C
      DIMENSION A(NROWA,NCOLA),B(NCOLA,NCOLB),C(NROWA,NCOLB) R0
      REAL
      DO 20 I=1,MA
      DO 20 J=1,NB
        X=0.
        DO 10 K=1,NA
          X=X+A(I,K)*B(K,J)
        DO 20 C(I,J)=X
      RETURN
      END
00047
00047

```

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```

00133 IF ( ABS(DELTA).LT.UNDER) DELTA = 0.00E 00
00137 DELTA=PIV*DELTA
00141 IF ( ABS(PIV) .LE. TOL) GO TO 150
00143 IR(I)=J
00145 IC(J)=I
00146 PIV = 1.0E0/PIV
00150 A(I,J)=PIV
00153 DO 60 K = 1,N
00155 60 IF (K.NE.J)A(I,K)=A(I,K)*PIV
00166 DO 90 K = 1,N
00167 IF (K.EQ.I) GO TO 90
00171 PIV1 = A(K,J)
00175 DO 80 L = 1,N
00177 IF ( ABS(PIV1).LT.UNDER) PIV1=0.0E 00
00203 IF ( ABS(A(I,L)).LT.UNDER) A(I,L) = 0.00E 00
00217 80 IF (L.NE.J)A(K,L)=A(K,L)-PIV1*A(I,L)
00235 90 CONTINUE
00240 DO 100 K = 1,N
00241 100 IF (K.NE.I)A(K,J)=-PIV*A(K,J)
00253 S=S+1
00254 IF (S.LT.R)GO TO 30
00256 110 DO 140 I = 1,N
00260 K=IC(I)
00262 M=IR(I)
00263 IF (K.EQ.I)GO TO 140
00265 DELTA=DELTA
00266 DO 120 L = 1,N
00267 TEMP=A(K,L)
00273 A(K,L)=A(I,L)
00302 A(I,L)=TEMP
00306 DO 130 L = 1,N
00307 TEMP=A(L,M)
00314 A(L,M)=A(L,I)
00322 130 A(L,I)=TEMP
00330 IC(M)=K
00332 IR(K)=M
00333 140 CONTINUE
00336 150 IRANK=S
00337 RETURN
00340 END

```

R12D0035
R12D0036
R12D0037
R12D0038
R12D0039
R12D0040
R12D0041
R12D0042
R12D0043
R12D0044
R12D0045
R12D0046

R12D0047
R12D0048
R12D0049
R12D0050
R12D0051
R12D0052
R12D0053
R12D0054
R12D0055
R12D0056
R12D0057
R12D0058
R12D0059
R12D0060
R12D0061
R12D0062
R12D0063
R12D0064
R12D0065
R12D0066
R12D0067
R12D0068
R12D0069
R12D0070

```

SURROUTINE NRTRM(LAY,SG,F,G,H,I)
C
C ROUTINE NRTRM COMPUTES ELEMENTS OF DERIVATIVE MATRIX IN
C NEWTON-RAPHSON ANALYSIS
C
00011 REAL SG(60,1)
00011 REAL E11(20),E22(20),V12(20),V21(20),G12(20),
00011 SCY(20),STY(20),TY(20)
00011 1 DIMENSION
00011 1 S11(20),S12(20),S21(20),S22(20),
00011 2 S1S(20),COS2(20),SIN2(20),COS2(20),
00011 F(3,20),G(3,20),H(3,20)
00011 COMMON /SET01/ E11,E22,V12,V21,G12
00011 COMMON /SET06/ SIN2,COS2,S1S,COS2
00011 COMMON /SET08/ S11,S22,S12,S21
00011 COMMON /SET10/ STY,SCY,TY,XM,XN
C
N = LAY
T12S = (SG(I+2*N,1)/TY(I))**2
T12D = SG(I+2*N,1)/TY(I)**2
T22S = (SG(I+N,1)/TY(I))**2
T22D = SG(I+N,1)/TY(I)**2
C12T = SG(I+2*N,1)*SG(I+N,1)/TY(I)**2
IF(SG(I+N,1) = 0.0) 1,2,2
1 VAL = SCY(I)*1.0E-60
RAT = SG(I+2*N,1)*SG(I+N,1)/SCY(I)
VAL = ABS(VAL)
RAT = ABS(RAT)
IF(RAT.LE.VAL) RAT=0.0E00
C12S = RAT/ SCY(I)
TS22S = (SG(I+N,1)/SCY(I))**2
GO TO 3
2 VAL = STY(I)*1.00E-60
RAT = SG(I+2*N,1)*SG(I+N,1)/STY(I)
VAL = ABS(VAL)
RAT = ABS(RAT)
IF(RAT.LE.VAL) RAT=0.0E00
C12S=RAT/STY(I)
TS22S = (SG(I+N,1)/STY(I))**2
3 S12S = T12S +TS22S
IF(ABS(S12S).LT.1.00E-20) GO TO 40
PN12 = S12S**((XM-1.)/2.)
PN32 = S12S**((XM-3.)/2.)
PM12 = S12S**((XM-1.)/2.)
PM32 = S12S**((XM-3.)/2.)
GO TO 80
40 CONTINUE
PN12 = 0.
PN32 = 0.
PM12 = 0.
PM32 = 0.
80 CONTINUE
C
00164 SNS = S1S(I)
00166 CSS = COS2(I)

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00167      SN2 = SIN2(I)
00171      CS2 = COS2(I)
      C
00172      F(1,I) = S11(I)*CSS + S21(I)*SNS
00177      F(2,I) = S12(I)*CSS + SNS/F22(I) + SNS/E22(I)*PN12
      1      + SNS*TS22S*(XM-1.)/E22(I)*PN32
      2      - SN2*(XM-1.)/(2.*G12(I))*PM32*CI2S
00227      F(3,I) = -SN2/(2.*G12(I)) - SN2/(2.*G12(I))*PM12
      1      - SN2*TI2S*(XM-1.)/(2.*G12(I))*PM32
      2      + CI2I*(XM-1.)/E22(I)*PN32
00253      G(1,I) = S11(I)*SNS + S21(I)*CSS
00260      G(2,I) = SNS*S12(I) + CSS/F22(I) + PN12*CSS/E22(I)
      1      + CSS * (XM-1.)*PN32/E22(I)*TS22S
      2      + (XM-1.)*CI2S*SN2*PM32/(2.*G12(I))
00310      G(3,I) = SN2/(2.*G12(I)) + SN2*PM12/(2.*G12(I))
      1      + SN2*(XM-1.)/(2.*G12(I))*PM32*TI2S
      2      + (XM-1.)*CI2I*PN32*CSS/F22(I)
00334      H(1,I) = (S11(I)-S21(I))*SN2/2.
00343      H(2,I) = S12(I)*SN2/2. - SN2/(2.*E22(I)) - PN12*SN2
      1      / (2.*E22(I)) - (XM-1.)*PN32*SN2/(2.*E22(I))
      2      + TS22S
      3      + CS2/(2.*G12(I))
00373      H(3,I) = CS2/(2.*G12(I)) + PM12*CS2/(2.*G12(I))
      1      + (XM-1.)*PM32
      2      - (XM-1.)*CI2I*PN32
      3      + TI2S*CS2/(2.*G12(I))
      4      + SN2/(2.*E22(I))
      C
00421      RETURN
00422      END

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```

C      SUBROUTINE CONVR(LAY,SG,SG1,KSG,IRTN)
C      ROUTINE CONVR CHECKS FOR CONVERGED SOLUTION DURING NEWTON-RAPHSON
C      ANALYSIS. ALSO CHECKS ITERATION LIMIT AND DIVERGENCE LIMIT.
C
000010      DIMENSION SG(60,1),SG1(60,1),DIF(60)
000010      COMMON /SET11/ EPS,UPRD,NIT,IT,SMLT
C
000010      ICON = 1
000011      N = LAY
000012      LT3 = LAY*3
000013      IRTN=1
C
C      CONVERGENCE CHECK
000014      DO 375 J3=1,LT3
000016      SUR = ABS(SG(J3,1))- ABS(SG1(J3,1))
000024      IF(SG1(J3,1).EQ.0.0E0) GO TO 330
000026      DIF(J3) = ABS(SUB/SG1(J3,1))
000031      GO TO 335
000032      330 CONTINUE
000032      DIF(J3) = SUR
000032      335 CONTINUE
000034      IF(NIF(J3).GT.EPS) GO TO 340
000040      GO TO 375
C
C      ITERATION CHECK
000040      340 CONTINUE
000040      IF((NIT-IT).NE.0) GO TO 350
000042      ICON = 3
000043      IF(NIF(J3).LE.UPRD) GO TO 375
000046      ICON = 4
000047      GO TO 375
C
C      DIVERGENCE CHECK
000050      350 IF(NIF(J3).LE.UPRD) GO TO 370
000053      ICON = 4
000054      GO TO 375
C
C
000055      370 CONTINUE
000055      ICON = 2
000056      375 CONTINUE
C
000061      GO TO (500,400,382,386),ICON
C
C      NON-CONVERGENCE DUMP
000071      382 CONTINUE
000071      WRITE(6,1720)
000075      WRITE(6,1722) EPS
000103      GO TO 395
000107      386 CONTINUE
000107      WRITE(6,1730)
000113      WRITE(6,1722) UPRD
000121      395 CONTINUE

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```

000121      NITP = NIT - 1
000123      WRITE(6,1741) NIT,NITP
000133      WRITE(6,1742)
000137      DO 397 I=1,LAY
000144      WRITE(6,1550) I,SG(I,1),SG(I+N,1),SG(I+2*N,1),SG(I,1),SG(I+N,1),
1          SG(I+2*N,1),DIF(I),DIF(I+N),DIF(I+2*N)
000241      397 CONTINUE
000247      IRTN=3
000250      RETURN
000251      400 IRTN=2
500 RETURN
C
000252      1550 FORMAT (I4,I1X,2(3E13.5,4X),3E13.5)
000252      1720 FORMAT (* SOLUTION FOR STRESS DOES NOT CONVERGE*)
000252      1722 FORMAT (* RELATIVE ERROR .GI.%,E15.5)
000252      1730 FORMAT (* SOLUTION FOR STRESS DIVERGES*)
000252      1741 FORMAT (/18X,*(ITERATION *,I3,*,*(ITERATION *,I3,*,*)
000252      1742 FORMAT ( (* LAYER*,4X,*SGM X*,8X,*SGM Y*,8X,*SGM XY*,11X,*SGM X*,
1          AX,*SGM Y*,8X,*SGM XY*,11X,*REL X*,8X,*REL Y*,8X,
2          *REL XY*/)
END
000252

```

```

C SURROUTINE LAMTST(LAY,SG,SGS,EPN,PS,KSG,KSGM,IFCN,UFAIL,FAC,SW)
C ROUTINE LAMTST PERFORMS FAILURE ANALYSIS, STIFFNESS TEST, ULTIMATE
C STRESS, ULTIMATE STRAIN, AND QUADRATIC INTERACTION
C
C * VARIABLE DICTIONARY *
C
C UFAIL(I) : INDICATE FAILURE UNDER SEPARATE MODES
C IFCN : FOR MULTI-MODE FAILURE ANALYSIS (I.E., IFCN=4)
C LFAIL : FAILURE ANALYSIS OPTION
C IJJ : FAILURE MODE
C KJJ : ORIENTATION OF STRESS FAILURE
C QIT(I) : ORIENTATION OF STRAIN FAILURE
C QPV(I) : QUADRATIC INTERACTION TERM FOR LAYER I
C FAC : QUADRATIC INTERACTION TERM FOR LAYER I PROV.LOAD
C IST : INTERPOLATION FACTOR
C ISV : STORE LAYER NO. AT FAILURE
C KSV : STORE STRESS ORIENTATION NO. AT FAILURE
C
C *****
C DIMENSION SG(60,1),SGS(60)
C DIMENSION EPS11(20),FPS22(20),EPS12(20)
C DIMENSION P11(20),P22(20),P12(20),
C 1 ULT(6,2),ULTIMA(6,2,20),
C 1 EP11(20),EP22(20),EP12(20)
C DIMENSION QIT(20),QPV(20)
C DIMENSION A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
C DIMENSION EPN(60,1),PS(60)
C INTEGER UFAIL(3),SW,T
C
C COMMON /SET03/EP11,EP22,EP12
C COMMON /SET04/ S011,S022,S012,SM11,SM22,SM12
C COMMON /SET05/ ULTIMA,STIFF
C COMMON /SET07/EP11,EP22,EP12
C COMMON /SET14/ A11,A22,A44,A12,B1,B2
C
C EVALUATE QUADRATIC INTERACTION COEFFICIENTS IF QUAD. INTER. FAILURE
C IF((IFCN.EQ.3).OR.(IFCN.EQ.4)) CALL QUADCF(LAY)
C IST = 1
C LFAIL = 0
C IPT = 1
C
C 500 CONTINUE
C NO 475 J=IST,LAY
C T = I
C
C NO 550 II=1,6
C NO 550 JJ=1,2
C ULT(II,JJ) = ULTIMA(II,JJ,I)
C 550 CONTINUE
C
C TEST 1: STIFFNESS TEST

```

```

000054 IF(KSG,EQ,1) GO TO 560
000060 IF(S011,EQ,0.0E0) GO TO 560
000061 RATIO = ABS(SM11/EP11(I)-FPS11(I))
000065 IF(RATIO,LT,STIFF) GO TO 677
C TEST 2: ULTIMATE STRESS
C ULT(1,1): MAX. AXIAL TENS.
C ULT(2,1): MAX. TRAN. TENS.
C ULT(3,1): MAX. SHEAR
560 CONTINUE
IF(.NOT.((IFCN,EQ,1).OR.(IFCN,EQ,4))) GO TO 570
IF(UFAIL(1),EQ,1).AND.(IFCN,EQ,4)) GO TO 570
IJJ=1
IF(SG(I,1)-0.0) 1,1,2
1 IF(ABS(SG(I,1))-ULT(1,2))3,679,679
2 IF(ABS(SG(I,1))-ULT(1,1))3,679,679
3 K= I+LAY
IJJ=2
IF(SG(K,1)-0.0)4,4,5
4 IF(ABS(SG(K,1))-ULT(2,2))6,679,679
5 IF(SG(K,1))-ULT(2,1))6,679,679
6 K= I+2*LAY
IJJ=3
IF(ABS(SG(K,1))-ULT(3,1))570,679,679
C
C TEST 3: ULTIMATE STRAIN
C ULT(4,1): MAX. AXIAL TENS.
C ULT(5,1): MAX. TRAN. TENS.
C ULT(6,1): MAX. SHEAR
570 CONTINUE
IF(.NOT.((IFCN,EQ,2).OR.(IFCN,EQ,4))) GO TO 580
IF(UFAIL(2),EQ,1).AND.(IFCN,EQ,4)) GO TO 580
KJJ=1
IF(EPN(I,1)-0.0) 71,71,72
71 IF(ABS(EPN(I,1))-ULT(4,2))73,689,689
72 IF(ABS(EPN(I,1))-ULT(4,1))73,689,689
73 CONTINUE
K= I+LAY
KJJ=2
IF(EPN(K,1)-0.0) 74,74,75
74 IF(ABS(EPN(K,1))-ULT(5,2))76,689,689
75 IF(EPN(K,1))-ULT(5,1))76,689,689
76 CONTINUE
K= I+2*LAY
KJJ=3
IF(ABS(EPN(K,1))-ULT(6,1))580,689,689
C
C TEST 4: QUADRATIC INTERACTION
C
580 CONTINUE
IF(.NOT.((IFCN,EQ,3).OR.(IFCN,EQ,4))) GO TO 590
IF(UFAIL(3),EQ,1).AND.(IFCN,EQ,4)) GO TO 590
GIT(I) = A11(I)*SG(I,1)**2 + A22(I)*SG(I+LAY,1)**2
1 +A44(I)*SG(I+2*LAY,1)**2 + A12(I)*SG(I,1)*SG(I+LAY,1)
2 +A1(I)*SG(I,1) + A2(I)*SG(I+LAY,1)
IF(GIT(I).GT,1.0) GO TO 699

```

```

000316 C 590 CONTINUE
000316 C
000316 675 CONTINUE
000321 IF (LFAIL.NE.0) GO TO R10
000322 WRITE(6,1995)
000325 RETURN

000326 SET INDICATOR OF FAILURE MODE
000327 677 LFAIL = 1
000327 KSG = KSGM
000334 GO TO 700
000335 679 LFAIL = 2
000336 IST = T
000340 GO TO 700
000340 689 LFAIL = 3
000341 IST = T
000343 GO TO 700
000343 699 LFAIL = 4
000344 IST = T
000346 QPV(T) = A11(T)*SGS(T) **2 + A22(T)*SGS(T+LAY) **2
* +A44(T)*SGS(T+2*LAY) **2 + A12(T)*SGS(T) *SGS(T+LAY)
* +B1(T)*SGS(T) + B2(T)*SGS(T+LAY)

000401 C PRINT FAILURE MODE
000401 C
000401 700 CONTINUE
000401 IF(IPT.EQ.1) WRITE(6,1990)
000413 IPT = 0
000414 IF(IFCN.NE.4) KSG=KSGM
000420 GO TO (701,703,723,743), LFAIL
000430 701 WRITE(6,1450)
000434 GO TO R50
000440 703 CONTINUE
000440 ISV = IJJ
000442 GO TO(704,705,706),IJJ
000450 704 WRITE(6,1452)
000454 GO TO 799
000460 705 WRITE(6,1453)
000464 GO TO 799
000470 706 WRITE(6,1454)
000474 GO TO 799

000500 C
000500 723 CONTINUE
000500 KSV = KJJ
000502 GO TO (724,725,726), KJJ
000510 724 WRITE(6,1462)
000514 GO TO 799
000520 725 WRITE(6,1463)
000524 GO TO 799
000530 726 WRITE(6,1464)
000534 GO TO 799

000540 C
000540 743 WRITE(6,1472) QIT(T),I,QPV(T),T
000554 C 799 CONTINUE

```

LAMTST

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```

000554 IF (IFCN.NE.4) GO TO 850
000562 LFM = LFAIL-1
000564 UFAIL(LFM) = 1
000566 IF (UFAIL(1).EQ.1).AND.(UFAIL(2).EQ.1).AND.(UFAIL(3).EQ.1))
      KSG = KSGM
      GO TO 500
000605 R10 CONTINUE
000606 IF (KSG.EQ.1) GO TO 850
000610 SW = 1
000611 IF (LFAIL.EQ.2) FAC = SINT(SG,SGS,ISV,1,IST,LAY)
000624 IF (LFAIL.EQ.3) FAC = SINT(EPS,PS,KSV,2,IST,LAY)
000637 IF (LFAIL.EQ.4) FAC = (1.0-QPV(IST))/(QIT(IST)-QPV(IST))
000646 850 WRITE(6,1495)

C
000652 1450 FORMAT (// * LAMINATE HAS FAILED * STIFFNESS TEST FAILURE*)
000652 1452 FORMAT (// * LAMINATE HAS FAILED * SG 11 EXCEEDS MAXIMUM*)
000652 1453 FORMAT (// * LAMINATE HAS FAILED * SG 22 EXCEEDS MAXIMUM*)
000652 1454 FORMAT (// * LAMINATE HAS FAILED * SG 12 EXCEEDS MAXIMUM*)
000652 1462 FORMAT (// * LAMINATE HAS FAILED * EP 11 EXCEEDS MAXIMUM*)
000652 1463 FORMAT (// * LAMINATE HAS FAILED * EP 22 EXCEEDS MAXIMUM*)
000652 1464 FORMAT (// * LAMINATE HAS FAILED * EP 12 EXCEEDS MAXIMUM*)
000652 1472 FORMAT (// * LAMINATE HAS FAILED * QUADRATIC INTERACTION*)
      * FAILURE*/27X,*QUADRATIC = *F7.4,* FOR LAYER *,I2/
      27X,*QUADRATIC = *F7.4,* FOR LAYER *,I2*
      *
      * OF PREVIOUS LOAD*)
000652 1495 FORMAT (/* AT FIRST POST-FAILURE LOAD POINT*)
000652 1990 FORMAT (////)
000652 1995 FORMAT (1H0)

C
000652 RETURN
000653 1 END

```

```

SUBROUTINE QUADCF(LAY)
C
C   COMPUTES QUADRATIC FAILURE CRITERIA COEFFICIENTS
C
000003 DIMENSION      ULTIMA(6,2,20)
000003 DIMENSION      A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
000003 COMMON          /SET05/ ULTIMA,STIFF
000003 COMMON          /SET14/ A11,A22,A44,A12,B1,B2
C
000003 DO 100 IMTALY=1,LAY
000005   A11(IMTALY) = 1./ULTIMA(1,1,IMTALY)*ULTIMA(1,2,IMTALY)
000013   A22(IMTALY) = 1./ULTIMA(2,1,IMTALY)*ULTIMA(2,2,IMTALY)
000017   A44(IMTALY) = (1./ULTIMA(3,1,IMTALY))*2
000023   B1(IMTALY) = 1./ULTIMA(1,1,IMTALY) - 1./ULTIMA(1,2,IMTALY)
000027   B2(IMTALY) = 1./ULTIMA(2,1,IMTALY) - 1./ULTIMA(2,2,IMTALY)
000034   100 CONTINUE
C
000037   RETURN
000037   END

```

07/23/74

RUN VERSION 2.3 --PSR LEVEL 363--

```

000012 SUBROUTINE LAYSUB (A12,STY,SCY,TY,EP511,EP522,EP512)
000012 DIMENSION E11(20),E22(20),V12(20),V21(20),TG12(20),A12(20),
000012 1 STY(20),SCY(20),TY(20),EP511(20),EP522(20),EP512(20)
000012 DIMENSION TEL1(20),TE22(20),TG12(20),TV12(20),TA12(20),TSTY(20),
000012 1 TSCY(20),TTY(20)
000012 COMMON /SET01/ E11,E22,V12,V21,G12
000012 COMMON /SET17/ TEL1,TE22,TG12,TV12,TA12,TSTY,TSCY,TTY
000012 DO 10 I = 1,20
000012 E11(I) = TEL1(I)
000013 E22(I) = TE22(I)
000015 G12(I) = TG12(I)
000017 V12(I) = TV12(I)
000021 A12(I) = TA12(I)
000023 STY(I) = TSTY(I)
000025 SCY(I) = TSCY(I)
000027 10 TTY(I) = TTY(I)
000031 RETURN
000035 END
000036

```

```

0000011 REAL FUNCTION SINT(VAL,PREV,IOR,SS,I,N)
0000011
0000011 FUNCTION: SUBPROGRAM SINT DETERMINES INTERPOLATION FACTOR FOR
0000011 STRES OR STRAIN FAILURE
0000011
0000011 * VARIABLE DICTIONARY *
0000011
0000011 VAL(I,1) : VALUE OF STRESS OR STRAIN AFTER FAILURE
0000011 PREV(I) : VALUE OF STRESS OR STRAIN BEFORE FAILURE
0000011 FLEMT : ELEMENT OF STRESS OR STRAIN ARRAY WHICH HAS FAIL
0000011 SINT : INTERPOLATION FACTOR
0000011
0000011 *****
0000011 DIMENSION VAL(60,1),PREV(60),ULT(6,2,20)
0000011 COMMON /SET05/ ULT,STIFF
0000011 INTEGER SS,ELEMT
0000011
0000011 IF (SS.EQ.1) IOS=IOR
0000011 IF (SS.EQ.2) IOS=IOR+3
0000011 FLEMT = (IOR-1)*N + I
0000011
0000023 ISN=2
0000024 IF (VAL(FLEMT,1).GT.0.00) ISN=1
0000024
0000030 DPRV = ABS(PREV(ELEMT))
0000033 DDIF = ABS(VAL(ELEMT,1))-PREV(ELEMT))
0000036 SINT = (ULT(IOS,ISN,1)-DPRV)/DDIF
0000036
0000045 RETURN
0000046 FND

```


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